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Comparison of western North Pacific Tropical Cyclone aids using storm-related and synoptic parameters

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COMPARISON OF WESTERN NORTH PACIFIC TROPICAL CYCLONE AIDS USING STORM-RELATED AND SYNOPTIC PARAMETERS

by

Henry Jones

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Comparison of Western North Pacific Tropical Cyclone Aids Using Storm-related and Synoptic Parameters

by

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Lieutenant, United States Navy
B.S., United States Naval Academy, 1979

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ABSTRACT

The performance of four western North Pacific Ocean objective aids (One-way influence Tropical Cyclone Model-OTCM; Recurver analog-REC; Total analog-TOTL; and 500 mb steering-CY50) is evaluated using mean forecast error (MFE), systematic error and cross-track (CT) and along-track (AT) statistics. Stratification of these errors by storm-related (latitude, longitude, intensity, 12-h intensity change and size) and synoptic parameters through empirical orthogonal functions (700 mb easterlies/250 mb trough, 700 mb westerlies/250 mb trough, 700 mb easterlies/250 mb ridge, 700 mb westerlies/250 mb ridge) distinguishes between different conditions associated with tropical cyclone motion. The systematic and CT/AT error results reveal distinct biases for each objective aid: 1) OTCM (short-range rightward/slow and long-range leftward/fast); 2) REC (rightward/fast); TOTL (leftward/fast); and 4) CY50 (rightward/slow). The OTCM has the best performance as a result of a small systematic bias. The REC analog has large forecast errors on left-turning and straight-moving storms due to its selection of only recurving analogs. The selection of analogs from the total sample (TOTL) results in errors due to missed recurvature forecasts. Finally, the CY50 has the worst long-range skill because of the lack of the physics of OTCM and climatology influence of the analog techniques.

TABLE OF CONTENTS

I. INTRODUCTION 12

II. OBJECTIVE AIDS 14

III. THE DATA SET 16

A. BEST-TRACK AND FORECAST POSITIONS 16

B. STORM-RELATED PARAMETERS 16

C. SYNOPTIC PARAMETERS 17

IV. ERROR STATISTICS 22

A. MEAN FORECAST ERROR 22

B. SYSTEMATIC ERROR 22

C. CROSS-TRACK AND ALONG-TRACK ERROR COMPONENTS 23

D. CONTINGENCY AND CLASS-ERROR TABLES 23

E. M-SCORE 25

V. STORM-RELATED PARAMETER RESULTS 29

A. UNSTRATIFIED SAMPLE 29

1. Mean Error Results 29

2. Systematic Error Results 31

3. CT/AT Errors 34

4. Summary. 39

B. LATITUDE 40

1. Dynamical Model (OTCM) 40

2. Analogs (REC and TOTL) 43

3. Steering (CY50) 45

4. Guidance Summary 45

C. LONGITUDE 46

1. Dynamical Model (OTCM) 46

2. Analogs (REC and TOTL) 50

3. Steering (CY50) 51
4. Guidance summary 51
D. INTENSITY 52
1. Dynamical Model (OTCM) 52
2. Analogs (REC and TOTL) 56
3. Steering (CY50) 57
4. Guidance Summary 57
E. 12-HOUR INTENSITY CHANGE 58
1. Dynamical Model (OTCM) 58
2. Analogs (REC and TOTL) 59
3. Steering (CY50) 59
4. Guidance Summary 60
F. SIZE 63
1. Dynamical Model (OTCM) 63
2. Analogs (REC and TOTL) 65
3. Steering (CY50) 68
4. Guidance Summary 68

VI. SYNOPTIC PARAMETER RESULTS 69
A. UNSTRATIFIED SYNOPTIC SAMPLE 69
B. 700 MB EASTERLIES AND 250 MB TROUGH TO THE NORTH 74
1. Dynamical Model (OTCM) 74
2. Analogs (REC and TOTL) 74
3. Steering (CY50) 80
C. 700 MB WESTERLIES AND 250 MB TROUGH TO THE NORTH 80
1. Dynamical Model (OTCM) 80
2. Analogs (REC and TOTL) 83
3. Steering (CY50) 83
D. 700 MB EASTERLIES AND 250 MB RIDGE TO THE NORTH 87
1. Dynamical Model (OTCM) 87
2. Analogs (REC and TOTL) 87
3. Steering (CY50) 93

E. 700 MB WESTERLIES AND 250 MB RIDGE TO THE NORTH . . . 93
1. Dynamical Model (OTCM) . . . 93
2. Analogs (REC and TOTL) . . . 93
3. Steering (CY50) . . . 99
F. SUMMARY . . . 99

VII. CONCLUSIONS . . . 101
1. Summary . . . 101
2. Recommendations for research . . . 102

APPENDIX A: STORM-RELATED PARAMETER PERCENTAGE OF CLASS ERROR TABLES . . . 106

LIST OF REFERENCES . . . 137

INITIAL DISTRIBUTION LIST . . . 139

LIST OF TABLES

1. SUMMARY OF OBJECTIVE AID 24 H PERFORMANCE 103
2. SUMMARY OF OBJECTIVE AID 48 H PERFORMANCE 104
3. SUMMARY OF OBJECTIVE AID 72 H PERFORMANCE 105

LIST OF FIGURES

1.1 The standard array of JTWC's objective forecasting aids available to support a tropical cyclone warning (12 GMT 19 August 1983 Tropical storm Dom) 13

3.1 Location of latitude and longitude tercile cutpoints (thick lines) in the western North Pacific (Williams, 1986) 18

3.2 Second mode of the a) zonal wind field at 700 mb and b) meridional wind field at 250 mb. All values multiplied by 100 21

4.1 Definition of forecast and systematic error components (SX and SY). In this example, both SX and SY are negative 24

4.2 Definition of cross-track (CT) and along-track (AT) components at 72 h. In this example, CT is positive (right) and AT is negative (slow) with respect to the CLIPER extrapolated track 26

4.3 Example of a) 3 X 3 contingency table and b) percentage of class errors and M-score for the OTCM at 24 h (total sample) 28

5.1 Mean forecast errors relative to corresponding CLIPER forecast for the total sample of 356 objective aid forecasts 30

5.2 Systematic zonal (SX) and meridional (SY) errors for the total sample of 356 objective aid forecasts. Starting from the origin, the line symbols indicate 12 h intervals (12 to 72 h) 32

5.3 Time variations of CT and AT M-scores for the total sample of 356 objective aid forecasts 35

5.4 CT percentages of 0-,1- and 2-class errors (total sample) for each of the terciles of the best track distribution relative to CLIPER (L-left, C-center, R-right). M-score also indicated 36

5.5 As in Fig. 5.4. except for along-track (AT) components (S-slow, C-center, F-fast relative to CLIPER) 37

5.6 As in Fig. 5.1, except for latitude subsamples 41

5.7 As in Fig. 5.2, except for latitude subsamples 42

5.8 As in Fig. 5.3, except for latitude subsamples 44

5.9 As in Fig. 5.1, except for longitude subsamples 47

5.10 As in Fig. 5.2, except for longitude subsamples 48

5.11 As in Fig. 5.3, except for longitude subsamples 49

5.12 As in Fig. 5.1, except for intensity subsample 53

5.13 As in Fig. 5.2, except for intensity subsamples 54

5.14 As in Fig. 5.3, except for intensity subsamples 55

5.15 As in Fig. 5.1, except for 12-h intensity change subsamples 60

5.16 As in Fig. 5.2, except for 12-h intensity change subsamples 61
5.17 As in Fig. 5.3, except for 12-h intensity change subsamples 62
5.18 As in Fig. 5.1, except for size subsamples 64
5.19 As in Fig. 5.2, except for size subsamples 66
5.20 As in Fig. 5.3, except for size subsamples 67
6.1 Cylcone/anticylone patterns at 250 mb and corresponding 700 mb zonal flow 70
6.2 Mean forecast errors relative to corresponding CLIPER forecasts for the total synoptic sample of 181 objective aid forecasts 71
6.3 Systematic zonal (SX) and meridional (SY) errors for the total synoptic sample of 181 objective aid forecasts. Starting from the origin, the line symbols indicate 12 h intervals (12 to 72 h) 72
6.4 Time variations of the CT/AT M-scores for the total synoptic sample of 181 objective aid forecasts 73
6.5 As in Fig. 6.2, except for subgroup 1 75
6.6 As in Fig. 6.3, except for subgroup 1 76
6.7 As in Fig. 6.4, except for subgroup 1 77
6.8 CT percentage of 0-, 1- and 2-class errors of subgroup 1 for each of the terciles of the best track distribution relative to CLIPER (L-left, C-center, R-right) 78
6.9 As in Fig. 6.8, except for along-track (AT) components (S-slow, C-center, F-fast relative to CLIPER) 79
6.10 As in Fig. 6.2, except for subgroup 2 81
6.11 As in Fig. 6.3, except for subgroup 2 82
6.12 As in Fig. 6.4, except for subgroup 2 84
6.13 As in Fig. 6.8, except for subgroup 2 85
6.14 As in Fig. 6.9, except for subgroup 2 86
6.15 As in Fig. 6.2, except for subgroup 3 88
6.16 As in Fig. 6.3, except for subgroup 3 89
6.17 As in Fig. 6.4, except for subgroup 3 90
6.18 As in Fig. 6.8, except for subgroup 3 91
6.19 As in Fig. 6.9, except for subgroup 3 92
6.20 As in Fig. 6.2, except for subgroup 4 94
6.21 As in Fig. 6.3, except for subgroup 4 95
6.22 As in Fig. 6.4, except for subgroup 4 96
6.23 As in Fig. 6.8, except for subgroup 4 97
6.24 As in Fig. 6.9, except for subgroup 4 98

A.1 Cross-track (CT) percentages of 0-, 1- and 2-class errors of the latitude < 13°N subsample for each tercile of the best track distribution relative to CLIPER (L-left, C-Center, R-right) 107

A.2 As in Fig. A.1, except for along-track (AT) components (S-slow, C-center, F-fast relative to CLIPER) for latitude < 13°N subsample 108

A.3 As in Fig. A.1, except for latitudes between 13°N and 17°N 109

A.4 As in Fig. A.2, except for latitudes between 13°N and 17°N 110

A.5 As in Fig. A.1, except for latitude > 17°N 111

A.6 As in Fig. A.2, except for latitude > 17°N 112

A.7 As in Fig. A.1, except for longitude < 129°E 113

A.8 As in Fig. A.2, except for longitude < 129°E 114

A.9 As in Fig. A.1, except for longitude between 129 and 140°E 115

A.10 As in Fig. A.2, except for longitudes between 129 and 140°E 116

A.11 As in Fig. A.1, except for longitude > 140°E 117

A.12 As in Fig. A.2, except for longitude > 140°E 118

A.13 As in Fig. A.1, except for intensity < 55 kt 119

A.14 As in Fig. A.2, except for intensity < 55 kt 120

A.15 As in Fig. A.1, except for intensity between 55 and 90 kt 121

A.16 As in Fig. A.2, except for intensity between 55 and 90 kt 122

A.17 As in Fig. A.1, except for intensity > 90 kt 123

A.18 As in Fig. A.2, except for intensity > 90 kt 124

A.19 As in Fig. A.1, except for 12-h intensity change < 0 kt 125

A.20 As in Fig. A.2, except for 12-h intensity change < 0 kt 126

A.21 As in Fig. A.1, except for 12-h intensity change 0 to 5 kt 127

A.22 As in Fig. A.2, except for 12-h intensity change 0 to 5 kt 128

A.23 As in Fig. A.1, except for 12-h intensity change > 5 kt 129

A.24 As in Fig. A.2, except for 12-h intensity change > 5 kt 130

A.25 As in Fig. A.1, except for size < 135 n mi 131

A.26 As in Fig. A.2, except for size < 135 n mi 132

A.27 As in Fig. A.1, except for size between 135 and 220 n mi 133

A.28 As in Fig. A.2, except for size between 135 and 200 n mi 134

A.29 As in Fig. A.1, except for size > 220 n mi 135

A.30 As in Fig. A.2, except for size > 220 n mi 136

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Finally, I would like to dedicate this work to my wife, Florence. She managed to give me encouragement when I needed it the most.

I. INTRODUCTION

Duty forecasters at the Joint Typhoon Warning Center (JTWC) on Guam have a variety of objective aids available to support tropical cyclone warnings. The selection of the most appropriate aid is often difficult because objective track forecasts usually conflict (Fig. 1.1). The trend toward addition of more aids will simply cause greater confusion. Tsui (1984) has indicated that optimum utilization of existing aids would lead to less confusion and a significant reduction in annual mean forecast errors. This deduction is based on the assumption that the current individual aids have potential skill. Therefore, forecasters need to be aware of the attributes of the objective aids under different conditions so that potential conflicts in guidance can be resolved.

Tsui (1984) and Elsberry and Peak (1986) have analyzed the performance of operational forecast aids in the western North Pacific. In addition to forecast error, their studies considered track and speed errors in determining the best objective track forecast technique. JTWC publishes annually a summary of the performance of the objective aids based on average forecast errors only. Recently, Williams (1986) and Chan et al. (1986) have analyzed the performance of the Nested Tropical Cyclone Model (NTCM) for different storm-related parameters. However, the accuracy of the other aids under different synoptic and storm-related conditions has not been examined. This study represents a first attempt in this effort.

The objectives of this study are: 1) to establish "rules of thumb" for each aid under various synoptic and storm-related conditions; 2) to provide objective aid attributes that will assist in the modification of existing aids and the development of improved techniques; and 3) to provide guidance in the building of a "decision tree" algorithm for objectively selecting the best aid (Peak and Elsberry, 1985). A brief description of the objective aids selected for this study will be presented in Chapter II. The storm-related and synoptic factors to be used in evaluating the aids will be discussed in Chapter III.

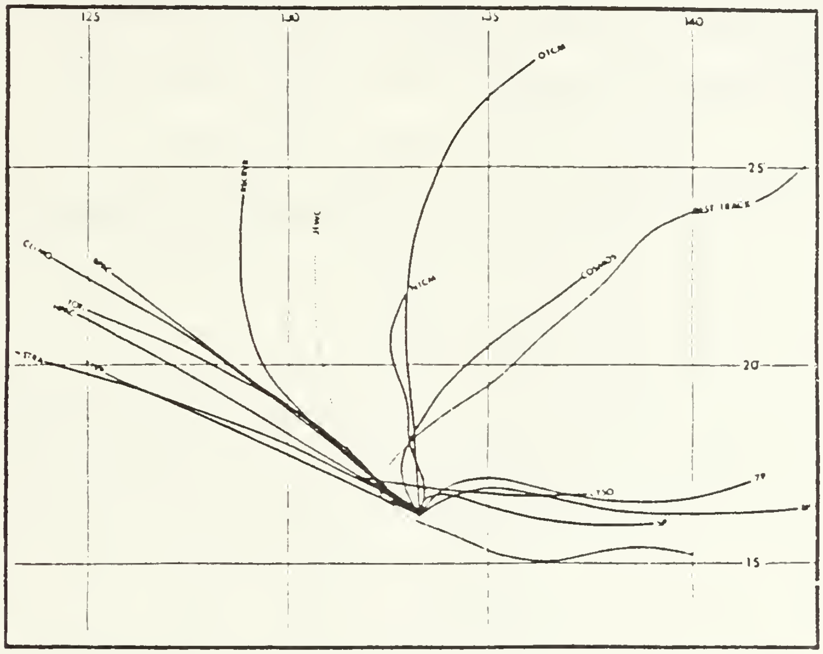

Figure 1.1 The standard array of JTWC's objective forecasting aids available to support a tropical cyclone warning (12 GMT 19 August 1983 Tropical storm Dom).

II. OBJECTIVE AIDS

There are four categories of objective techniques for predicting tropical cyclone motion: 1) climatology-persistence; 2) steering flow; 3) statistical; and 4) numerical. Currently, JTWC has twelve objective aids available for tropical cyclone track guidance:

1) four climatology and persistence programs (Climatology-CLIMO; Extrapolation-XTRP; Half persistence and climatology-HPAC; and Blended persistence and climatology-BPAC)

2) three steering flow programs based on 500, 700 and 850 mb geopotentials (CY50, CY70 and COSMOS);

3) three analog programs (Recurver-REC; Straight-STRA; and Total-TOTL)

4) two numerical tropical cyclone models (Nested Tropical Cyclone Model-NTCM and One-way influence Tropical Cyclone Model-OTCM).

A complete description of these aids are given in the JTWC Annual Tropical Cyclone Report (Joint Typhoon Warning Center, 1985).

Only four (OTCM, REC, TOTL, CY50) of the JTWC aids were selected for use in this study for the years 1981 to 1983. CY50 was the only steering program archived in 1983 and COSMOS was undergoing testing and evaluation during 1983. The inclusion of either CLIM, HPAC or BPAC would have further reduced the size of the homogeneous data set due to missing verifying positions. The Nested Tropical Cyclone model (NTCM) was evaluated in a study by Chan et al. (1986). Since the completion of that study, NTCM has undergone various modifications, and it was not possible to recompute the desired forecasts (1981 to 1983) with the most recent version. Because the emphasis in this study is placed on forecasting turning motion, the STRA and XTRP techniques are excluded based upon a study by Elsberry and Peak (1986), who showed that these aids performed poorly for turning storms and long-range forecasts, respectively. Thus, four basic categories of objective techniques are represented by the aids evaluated in this study:

1) numerical (OTCM);
2) steering flow (CY50);
3) climatological analog (REC, TOTL); and
4) climatology-persistence (CLIPER).

The western North Pacific CLIPER (actually WPCLPR) technique that was developed by Xu and Neumann (1985) is used as a normalized or no-skill aid to provide a benchmark with which to assess the skill of other aids. This prediction scheme is based on a series of regression equations using predictors derived from climatology (storm location and time of year), persistence (average storm motion over the past 12 and 24 h) and storm intensity (maximum sustained surface wind). Forecasts in the first 24 h rely heavily on persistence, with increasing emphasis on climatology in the 48-h and 72-h forecast periods. A description of the applications of CLIPER to error statistics will be presented in Chapter IV.

III. THE DATA SET

A. BEST-TRACK AND FORECAST POSITIONS

Dr. T. Tsui and Mr. M. Fiorino of the Naval Envronmental Prediction Research Facility (NEPRF). provided the files of best-track information and objective aid forecasts. As in Chan et al. (1986), tropical cyclones in the western North Pacific between 1981 to 1983 are examined. A total of 356 cases are available, which represents only one-fifth of the approximately 2200 tropical cyclone warnings issued by JTWC during the 1981-1983 seasons. The requirement that a homogeneous sample be compared (Neumann and Pelissier, 1981a) is the primary reason for the low number of warnings. A second reason is that only forecasts that could be verified at 24, 48 and 72 hours are included in this study.

The errors of this homogeneous set of 356 forecasts are analyzed by comparing objective aid forecast positions to (1) best-track positions provided by JTWC and (2) the CLIPER forecasts, also provided by Mr. M. Fiorino. Following Chan et al. (1986), the CLIPER track is selected as a reference in calculating the cross-track (CT) and along-track (AT) components for each aid. The reason for using CLIPER is that it is a statistical scheme relatively free of any significant bias with respect to actual storm track.

B. STORM-RELATED PARAMETERS

The five storm-related parameters used by Chan et al. (1986) are also used in this study. These parameters include the latitude, longitude, intensity, 12-hour intensity change and size of the tropical cyclone. The parameters are extracted from warnings issued by JTWC and correspond to the initial times of the forecast. Warning positions are used because best-track information would be unavailable to forecasters in an operational environment. Frequency distributions of the five parameters have been shown in previous literature (e.g., Williams, 1986). As similar distributions of these parameters are found in this study, they will not be shown.

The five storm-related parameters are partitioned into the same terciles as in Chan et al. (1986). Error statistics are then computed for each subsample to determine differences in objective aid performance (see Chapter IV). The terciles divide the latitude data into three subsamples (Fig. 3.1): "southern" (< 13°N); "central" (between 13°N and 17°N); and "northern" (> 17°N) . The number of cases in each subsample is 103, 126 and 127, respectively. Longitude is divided into "western" (< 129°E), "middle" (between 129°E and 140°E) and "eastern" (> 140°E). The number of cases in each subsample is 113, 127 and 116, respectively.

The intensity is the estimated maximum sustained wind at warning time. The cutpoints divide the data into subsamples which shall be referred to as "weak" (< 55 kt), "moderate" (between 55 and 90 kt) and "intense" (> 90 kt). The number of cases in each subsample is 118, 104 and 134, respectively. The 12-h intensity change can be separated into "weakening" (< 0 kt), "developing" (between 0 and 5 kt) and "rapidly developing" (> 5 kt) subsamples. The number of cases are 71, 149 and 136, respectively. It is not possible to get nearly equal sample sizes in this case because the intensities are only recorded to the nearest 5 kt.

The final storm-related parameter (size) is defined to be the radius of 30 kt (15 m/s) winds. This parameter is contained in nearly all warnings issued by JTWC. When a warning contains more than one radius of 30 kt winds to represent the horizontal structure of the storm, the largest radius is selected. If no wind radii information is available (maximum speeds less than 30 kt), the cyclone is assumed to have a size of 55 km (30 n mi). The cutpoints separate the size data into three subsamples: "small" (< 135 n mi); "medium" (between 135 and 220 n mi) and "large" (> 200 n mi). The number of cases in these subsamples is 116, 115 and 125, respectively.

C. SYNOPTIC PARAMETERS

This study represents a first attempt at analyzing the performance of objective aids using synoptic parameters based on empirical orthogonal function (EOF) representation of the environmental wind fields. Chan et al. (1980) found that turning motion is controlled by large-scale flow fields surrounding the tropical cyclone. Recent studies (Shaffer and Elsberry, 1982; Peak and Elsberry, 1986; Peak et al., 1986) have demonstrated the application of EOF analysis to representation of the large-scale flow around a tropical cyclone. A detailed description of the EOF method is beyond the scope of this study. Descriptions of this method can be found in Shaffer and Elsberry (1982) and Peak et al. (1986).

The basic EOF technique consists of representing the environmental flow as a linear combination of principal components derived from a large number of synoptic

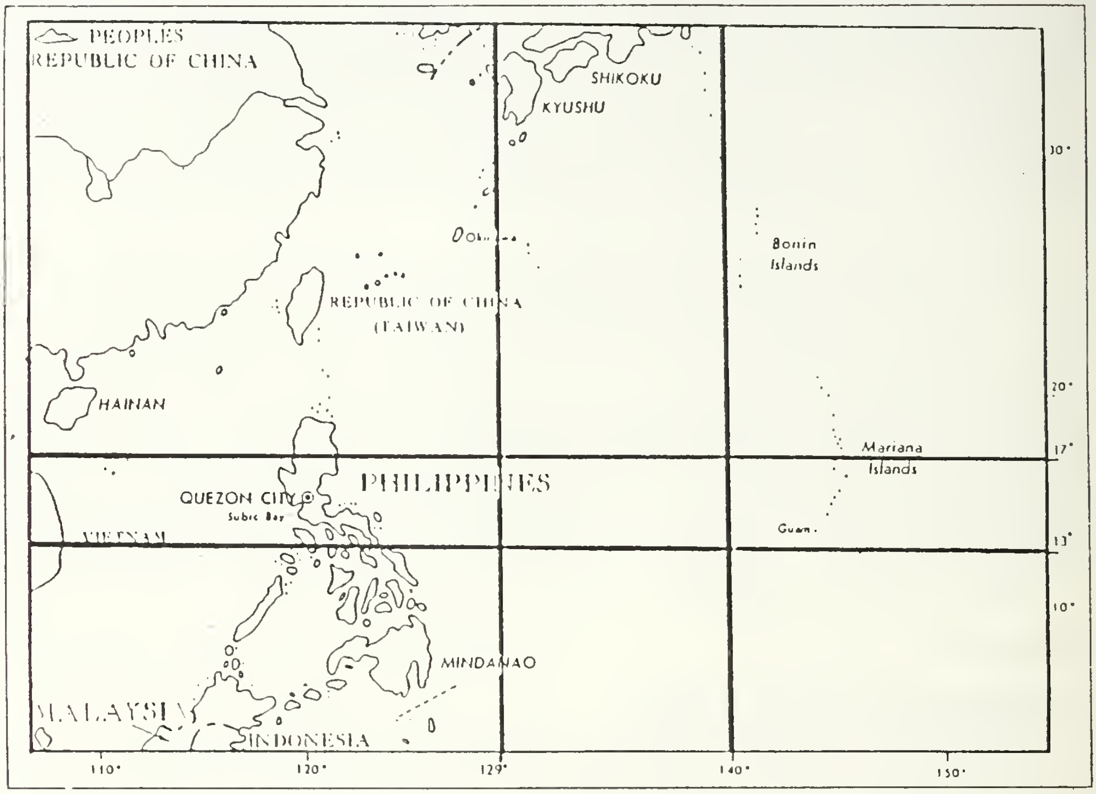

Figure 3.1 Location of latitude and longitude tercile cutpoints (thick lines) in the western North Pacific (Williams, 1986).

fields. For a particular case, the synoptic information may be efficiently represented by the summation of only a few products of EOF coefficients and eigenfunctions. Peak et al. (1986) used discriminant analysis to isolate the individual EOF components that best distinguish future zonal and meridional motion. The 700 mb zonal mode 2 (U700-2) and 250 mb meridional mode 2 (V250-2) components have been found to classify 67% and 62% of the cases into the correct zonal and meridional translation categories respectively (Peak et al., 1986).

The patterns of the 700 mb zonal (Fig. 3.2a) and 250 mb meridional (Fig. 3.2b) components can be interpreted separately as possible atmospheric flow patterns. A positive coefficient multiplying an eigenvector represents the pattern shown, whereas a negative coefficient would represent the exact inverse. There is no mathematical connection between a specific zonal-field mode and the same mode of the meridional field. Mode 2 of the 700 mb zonal flow (Fig. 3.2a) may be interpreted as a tropical cyclone embedded in a broad easterly flow. Farther to the north, the $U=0$ isoline indicates the position of the subtropical ridge line. Midlatitude westerly flow can be found farther north. Thus, this single mode may provide a realistic representation of the trade flow and large-scale midlatitude westerlies. Mode 2 of the 250 mb meridional flow (Fig. 3.2b) has alternating bands of positive and negative flow (trough-ridge-trough pattern). A positive coefficient multiplying the EOF field in Figure 3.2b would represent a synoptic pattern with a trough directly north of the cyclone, and ridges to the northwest and northeast. Because the grid is relocated each time relative to the tropical cyclone, there is no preferred location relative to the midlatitude troughs and ridges.

The EOF coefficients used in this study have been taken from the Peak et al. (1986) data set for 1981 to 1983. The cases are stratified into four categories based on positive and negative U700-2 and V250-2 coefficients. Since a change of sign indicates a completely different flow, positive and negative values of U700-2 and V250-2 coefficients represent different synoptic categories. Therefore, the four synoptic stratifications are:

1) U700-2 > 0.0 and V250-2 > 0.0 (i.e., low-level easterlies and upper-level trough to the north), 36 cases;
2) U700-2 < 0.0 and V250-2 > 0.0 (i.e., low-level westerlies and upper-level trough to the north), 38 cases;
3) U700-2 > 0.0 and V250-2 < 0.0 (i.e., low-level easterlies and upper-level ridge to the north), 51 cases; and

4) U700-2 < 0.0 and V250-2 < 0.0 (i.e., low-level westerlies and upper-level ridge to the north), 48 cases.

The total number of cases in this sample from 1981-1983 is 181, whereas the Peak et al. (1986) data set included 319 cases during 1979 to 1983. These cases are analyzed in Chapter VI using the same methods described for the storm-related parameters (see Chapter IV).

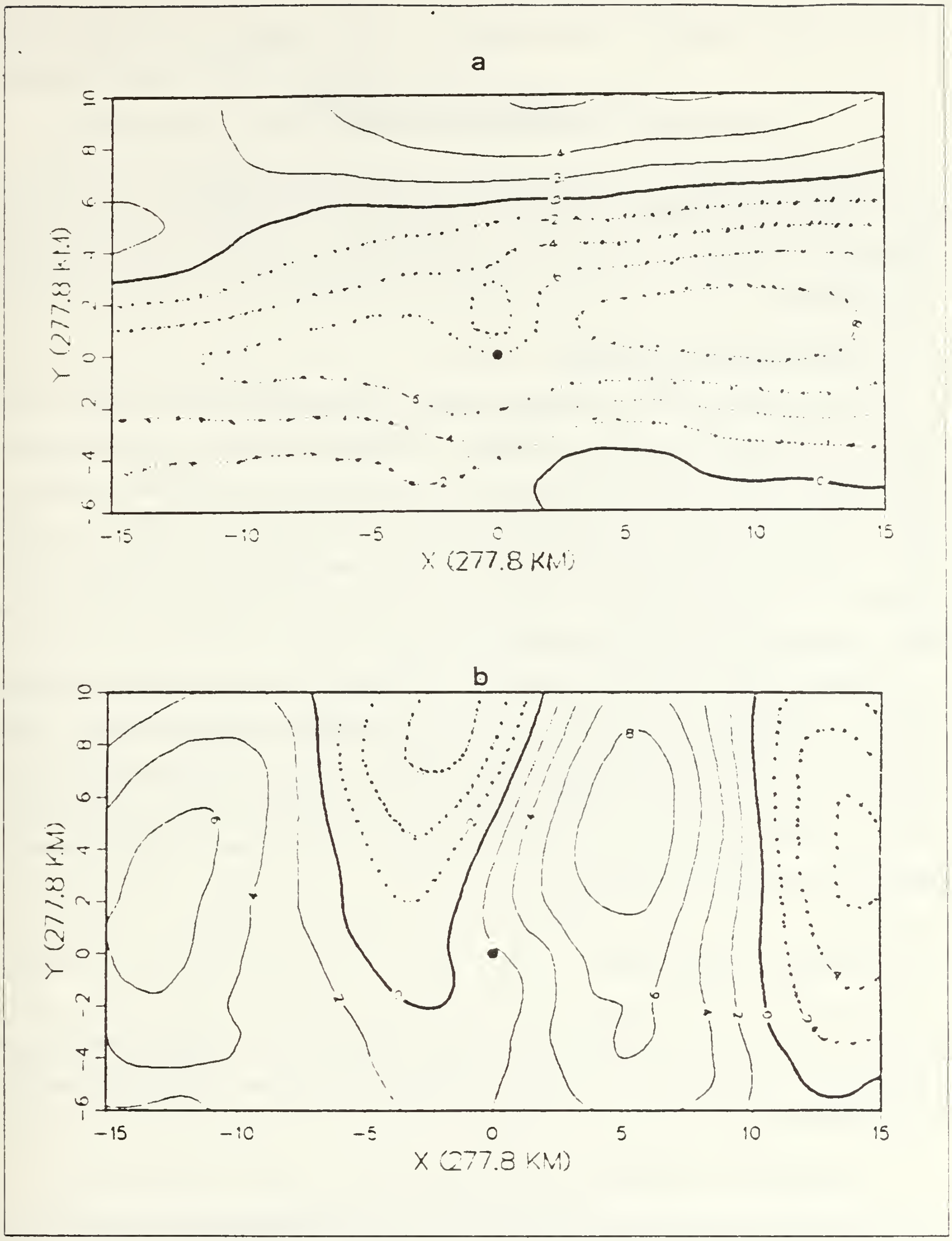

Figure 3.2 Second mode of the a) zonal wind field at 700 mb and b) meridional wind field at 250 mb. All values multiplied by 100. The dot indicates storm location.

IV. ERROR STATISTICS

Following Chan et al. (1986), the objective aids are evaluated in terms of: 1) mean forecast error (MFE) relative to CLIPER; 2) systematic zonal (SX) and meridional (SY) errors; and 3) cross-track (CT) and along-track (AT) errors relative to a CLIPER track.

A. MEAN FORECAST ERROR

Forecast error (FE) is commonly used to verify tropical cyclone forecasts. It is defined as the great circle distance between the forecast and best track (determined in post-season analysis) positions (Fig. 4.1). Mean forecast error (MFE) is simply the sum of the forecast errors divided by the number in the sample. The FE at 12, 24, 36, 48, 60 and 72 h for each objective aid and CLIPER are computed for the total sample and each subsample stratified by storm-related and synoptic paramters. The MFE and other error components will be expressed in kilometers.

Though MFE is useful as an absolute measure, it may not provide an assessment of forecast skill (e.g., exceed levels achieved by climatology and persistence). Thus, CLIPER is used as a normalizer, or no-skill model, to provide a benchmark to measure the skills of other objective techniques (Neumann and Pelissier, 1981a; Thompson et al., 1981). The differences are displayed in terms of percentage (P) improvement or deterioration relative to CLIPER:

$$P = 100\,(FEc - FEm)\,/\,FEc\,, \qquad (4.1)$$

where FEc is the CLIPER FE and FEm is the objective aid FE. Negative and positive percentages of (P) indicate deterioration and improvement over CLIPER, respectively (see Chapter V, Fig. 5.1).

B. SYSTEMATIC ERROR

Systematic error components (SX and SY) are defined as the zonal (δx) and meridional (δY) errors averaged over the total forecast sample (Fig. 4.1). These error components indicate the presence or absence of longitudinal or latitudinal error bias in the sample. A monotonic increase or decrease of error with forecast interval suggests the presence of a systematic error. If present, these systematic errors could be statistically removed (Peak and Elsberry, 1982).

C. CROSS-TRACK AND ALONG-TRACK ERROR COMPONENTS

Just as the systematic errors may suggest biases in the zonal and meridional directions, the cross-track (CT) and along-track (AT) errors provide information on the direction and speed of tropical cyclone movement relative to some reference track. Elsberry and Peak (1986) interpreted the CT components relative to a persistence forecast as turning motion and the AT components as speed of motion. When CT/AT components are calculated relative to a CLIPER (climatology and persistence) track, the CT and AT standard deviations are nearly equal at each forecast interval (Elsberry and Peak, 1986). In addition, the means in the CT distribution are nearly zero for all forecast periods (Chan et al., 1986). However, the mean AT values (not shown) indicate that the CLIPER positions are consistently in front of those of the best track. This is expected because any directional deviation of the storm track from the CLIPER track will lead to negative AT errors, even though the total displacements are identical (Neumann and Pelissier, 1981a). Since the primary emphasis is on turning motion (CT), the nearly symmetric CT distribution supports the use of CLIPER as a reference system, rather than the persistence forecast used by Elsberry and Peak (1986).

CT/AT components of the best track and objective aid forecast positions are calculated relative to a CLIPER forecast position at the corresponding time. In Figure 4.2, the CT/AT at 72 h is computed relative to a line connecting the 60-and 72-h CLIPER forecast positions. The perpendicular distance from the OTCM (or other objective aid) or best-track position to the CLIPER track is the CT component. Positive and negative values are to the right and left, respectively (looking downstream from the 60-h CLIPER forecast position). The AT component is the distance from the 72-h CLIPER forecast to the point at which the perpendicular from the OTCM (or best-track) position intersects the CLIPER track. The AT values are positive (negative) if the perpendicular meets the track ahead of (behind) the CLIPER position.

D. CONTINGENCY AND CLASS-ERROR TABLES

CT and AT components of the best track positions at 24, 48 and 72 h are divided into terciles (at the 33.3 and 66.7 percentiles). The motivation for the separation into terciles is that an objective aid should correctly distinguish between left-turning (L), straight-moving (C) and right-turning (R) storms (Elsberry and Peak, 1986). Thus, the

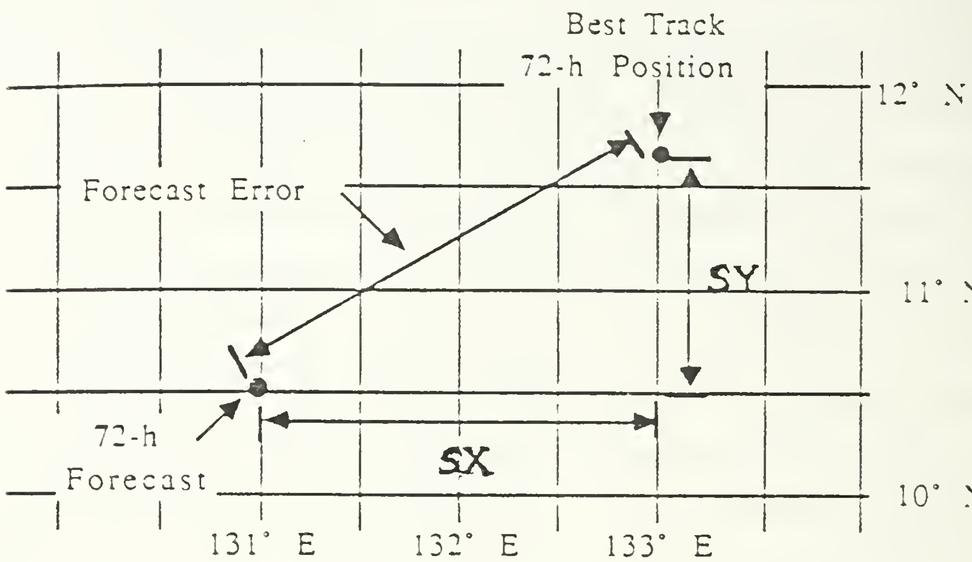

Figure 4.1 Definition of forecast and systematic error components (SX and SY). In this example, both SX and SY are negative.

CT tercile distributions are labeled as left (L), center (C) and right (R). The AT tercile distributions are slow (S), center (C) and fast (F).

The tercile (CT or AT) in which the objective aid forecast is found is then compared with that of the best track for each case in the sample. A 3 x 3 contingency table is formed for each component and forecast period (Fig. 4.3a). The number of cases along the diagonal from top-left to bottom-right represent "correct" forecasts and are referred to as zero-class errors. The two-class errors consist of objective aid forecasts on the opposite side of the CLIPER track compared to the best track. These errors are located in the upper-right and lower-left bins. The remaining bins contain one-class errors in which the objective aid forecast is displaced only one tercile from the best track. These percentages of each tercile class error for each component and forecast period may be summarized in a class-error table. For example, the percentage of OTCM two-class errors (Fig. 4.3b) for CT at 24 h is higher in the "L" tercile (26.5) than in the "R" tercile (12.8). This indicates that the two-class OTCM forecast errors are more likely to be to the right than to the left of the best track ("right bias").

The lower portion of the class-error table (Fig. 4.3b) summarizes the percentage of class errors for each category (L, C and R or S, C and F) of the sample. In the above example, the zero-, one- and two-class errors are 43.8%, 43.4% and 12.9%, respectively. If a purely random selection scheme had been used, the zero-, one- and two-class errors would have been 33.3%, 44.4% and 22.2%. Thus, this scheme has skill relative to random selection.

E. M-SCORE

A scoring system devised by Preisendorfer and Mobley (1982) is used to quantitatively measure the performance of the objective techniques. The skill of a particular aid can be characterized by a "penalty score" M:

$$M = V + 2W, \tag{4.2}$$

where U, V and W are the percentages of the zero-, one- and two-class errors, and $U + V + W = 100\ \%$. Thus, the M-score is a linear measure which penalizes an objective aid more (twice) for having a two-class error. The lower the M-score, the higher the degree of skill. For a random tercile selection, each of the nine bins in the

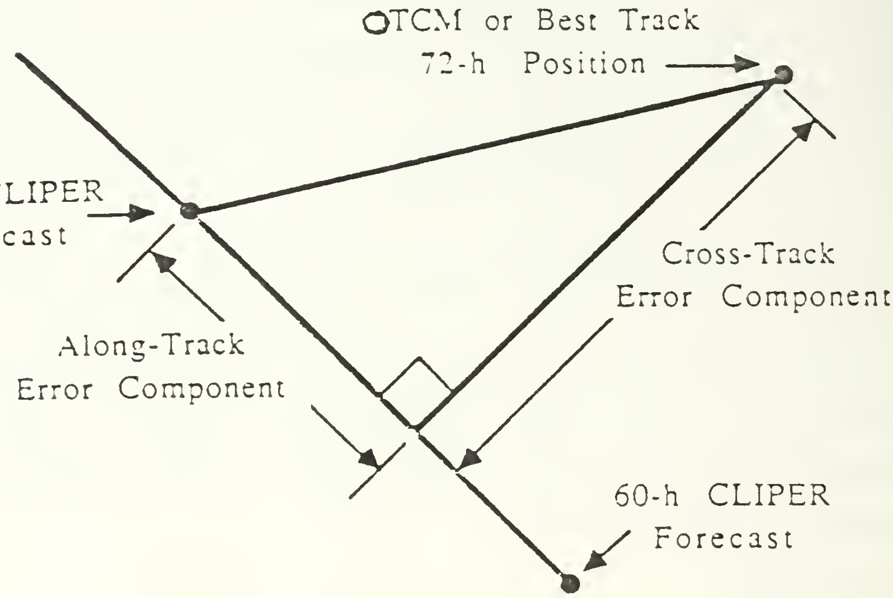

Figure 4.2 Definition of cross-track (CT) and along-track (AT) components at 72 h. In this example, CT is positive (right) and AT is negative (slow) with respect to the CLIPER extrapolated track.

contingency table would contain 1/9 of the sample. Therefore, a random selection would have an M-score of 88.9. In the previous example (Fig. 4.3b), the CT M-score for the OTCM is 69.1 at 24 h.

Since the CT/AT terciles are defined relative to CLIPER, the CLIPER forecast will always be in the center tercile. Thus, the CLIPER forecast will never have more than a one-class error, and the terciles by definition are constructed so that 66.7% of the cases are adjacent to the center tercile. For both CT and AT components, the M-score for CLIPER will always be 66.7%. In Fig. 4.3b, the OTCM CT forecast components are worse than those of CLIPER at 24 h (69.1).

a

24 h

Best Track	OTCM L	OTCM C	OTCM R	Total
L	41	45	31	117
C	25	38	59	122
R	15	25	77	117
Total	81	108	167	156

b

24 h

Best Track	OTCM %0	OTCM %1	OTCM %2
L	35.0	38.5	26.5
C	31.1	68.9	
R	65.8	21.4	12.8
Total	43.8	43.4	12.9

M Score = 69.1

Figure 4.3 Example of a) 3 X 3 contingency table and b) percentage of class errors and M-score for the OTCM at 24 h (total sample).

V. STORM-RELATED PARAMETER RESULTS

Objective aid performance in terms of storm-related parameters is presented in this chapter. Error statistics for the unstratified sample are discussed in the following order: 1) mean forecast error (MFE); 2) systematic error (SX, SY); and 3) CT/AT error. After the description of the unstratified (total) sample, the sample is then divided into three subsamples. For each stratified sample, error statistics are discussed for each individual aid. The stratifications are by latitude, longitude, intensity, 12-h intensity change and size samples. A performance summary is given at the conclusion of each sample discussion. For ease of comparison, figures of mean, systematic and CT/AT errors are collected at the end of this chapter. Due to the large number of contingency and class-error results (over 70 figures), only the class errors are shown. For ease of reference, the stratified class-error tables are collected in Appendix A.

A. UNSTRATIFIED SAMPLE

1. Mean Error Results

Dynamical Model (*OTCM*). The CLIPER MFE for 24, 48 and 72 h (183, 413 and 639 km) represent the standard of comparison. The mean error profiles (Fig. 5.1) indicate a close grouping of aid performance in the first 24 h. This close grouping of errors at 12 and 24 h may be a result of similar positioning errors. In their study of western North Pacific Ocean forecast errors, Jarrell et al. (1978) found that a 12 n mi increase in initial position error may be related to a 20 n mi increase average 24 h forecast error. The poor short-range performance of OTCM (10% worse than CLIPER) is probably a combination of initial positioning errors and errors that occur in the initialization of the model. In longer ranges, OTCM is 12% and 7% better than CLIPER at 48 and 72 h, respectively. The large errors in the early periods compared to relatively constant skill by OTCM between 36 h and 72 h tends to substantiate the existence of an initialization problem. Furthermore, OTCM's long-range skill demonstrates the superiority of dynamical models over other techniques such as analog and steering (Elsberry and Peak, 1986).

Steering (*CY50*). The short-range performance of CY50 (5% better than CLIPER) compared to the marginal, or no skill of the other aids, implies that the 500 mb steering flow may be the best indicator of initial cyclone motion. However, CY50

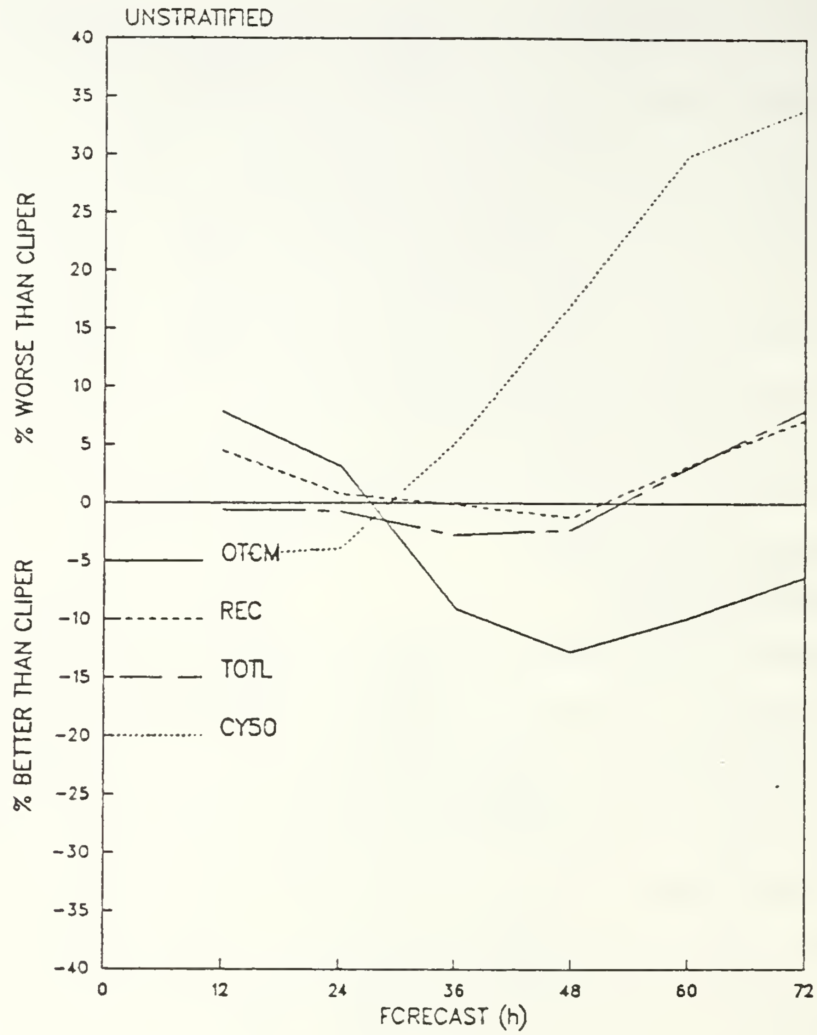

Figure 5.1 Mean forecast errors relative to corresponding CLIPER forecast for the total sample of 356 objective aid forecasts.

shows a sharp decline in skill after 24 h, and becomes 35% worse than CLIPER at 72 h. This unsophisticated steering technique, as compared to OTCM, can not account for various physical processes responsible for tropical cyclone motion (i.e., beta-effect, baroclinic processes, etc.). The OTCM numerically integrates these processes, while the analog techniques contain them implicitly through their climatological data records. Therefore, CY50 has the worse long-range objective aid performance.

Analogs (*REC and TOTL*). The performances of TOTL and REC are essentially similar to CLIPER (within 1 to 2%) in the 24 to 48 h period. These results for short-term forecasts are not unexpected since both CLIPER and analog methods use the same data base, and emphasize persistence in the early forecast periods (0 to 48 h). However, both analogs show little skill (10% worse than CLIPER) at the 72 h projection, which is similar to the analysis of Tsui (1984). Analog studies in the Atlantic region (Neumann and Pelissier, 1981b) and eastern Pacific area (Thompson and Elsberry, 1981) had similar results. In these studies, the analog methods had large forecast errors when the storm had an anomalous track, or an inadequate number of available analogs. The CLIPER model used in this study (WPCLPR) was designed to eliminate the problem in the analog method of lacking an insufficient number of analogs (Xu and Neumann, 1985). However, the problem of anomalous cyclone motion is not limited to the analog methods, but exists in all objective techniques. For example, errors in forecasting recurvature account for the largest errors in aid performance, especially at the 72 h projection. The slight decline in OTCM skill after 48 h, and poor performance of the other aids at 72 h, may be attributed largely to recurvature errors.

2. Systematic Error Results

Because the mean errors (MFE) do not provide any direction information, systematic error analysis is used as a method of introducing "directionality". Very small zonal (SX) and meridional (SY) errors are shown in Fig. 5.2 for short-term objective aid forecasts (9 to 36 km). These errors may be a result of initial positioning errors. However, the errors beyond 24 h acquire distinct profiles for each individual aid.

Dynamical Model (*OTCM*). Although small, the OTCM systematic error trend suggests an initial northeastward bias in the 24 h forecast period, followed by a westward track bias at the 72 h projection. The 24 h OTCM SX and SY errors (56 and 48 km) are similar to those found by Chan et al. (1986) for the NTCM. Unlike the

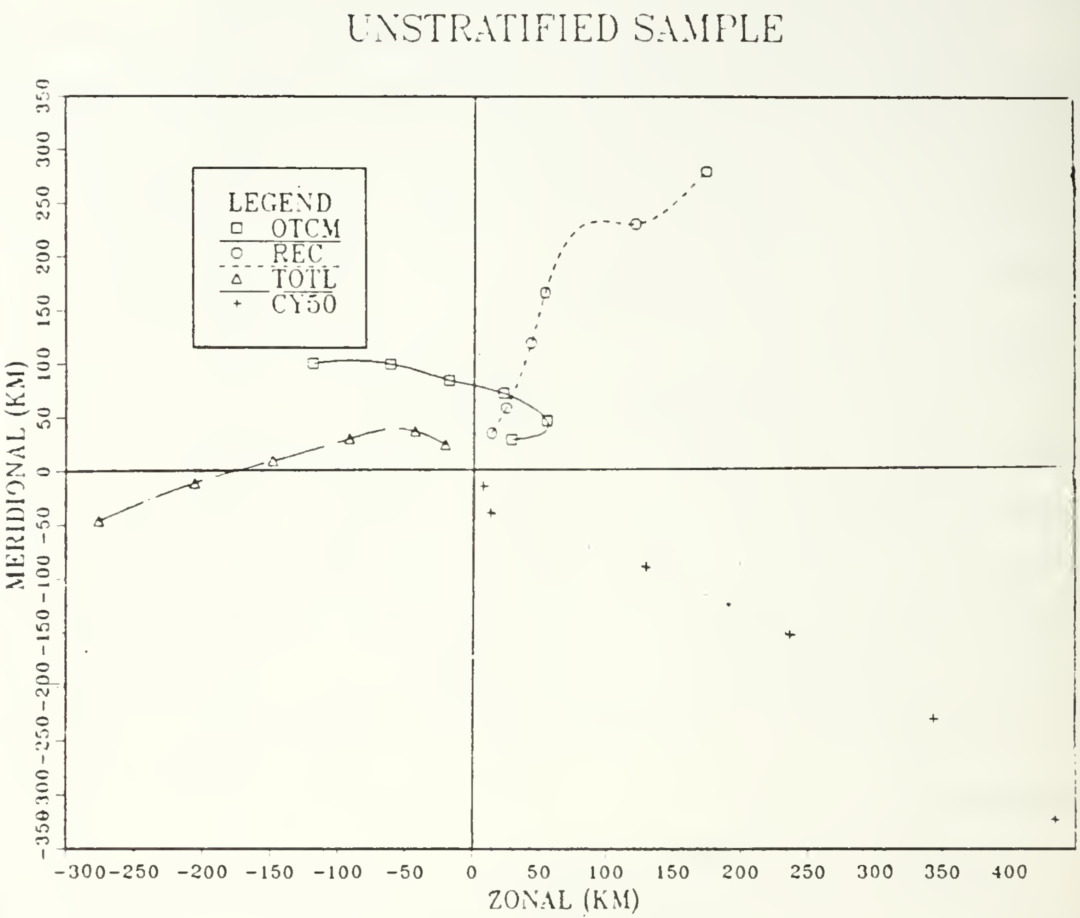

Figure 5.2 Systematic zonal (SX) and meridional (SY) errors for the total sample of 356 objective aid forecasts. Starting from the origin, the line symbols indicate 12 h intervals (12 to 72 h).

NTCM, the OTCM model has a negatively increasing SX error beyond 48 h , whereas NTCM's SX errors were insignificant. Similarly, NTCM has very small SY errors (-16 to 4 km), whereas OTCM SY errors increase monotonically from 48 km (at 24 h) to 102 km (at 72 h).

The OTCM westward bias at 72 h may be caused by a failure to fully predict the right-turning motion of recurving storms. Since NTCM is essentially a "nested" version of OTCM, the differences in biases in the NTCM may suggest that the pre-processing technique in the OTCM might be responsible (Shewchuk and Elsberry, 1978). The advantage of the pre-processing approach is that it improves the initial storm motion vector (eastward bias in OTCM). However, the disadvantage is that it always forces a persistence component into the model, whereas the storm actually may be decelerating or accelerating.

Analogs (REC and TOTL). The REC aid has the largest, positive SY errors of any aid. The 36 h SY error is 121 km compared to a SX error of only 45 km. By 72 h, the REC SY error increases to 280 km with a corresponding SX error of 177 km. These results imply that REC has an excessive northward bias for the typical storm motion toward the northwest. Elsberry and Peak (1986) found that the selection of analogs from only recurving tracks (REC) results in large rightward (northward) track biases. Leftward biases were found for the STRA aid (not shown), which selects only those analogs that are "straight-movers".

In contrast to REC, TOTL has large, negative SX errors, and only small SY errors. The maximum SY value is -46 km (72 h), while SX values increase to -275 km by 72 h. TOTL's systematic error profile (Fig. 5.2) suggests the existence of a westward bias for the typical cyclone track. A similar westward bias was found in previous studies of analog aids (Neumann and Leftwich, 1977; Renard and Bowman, 1976). Elsberry and Peak (1986) suggest that selecting the analog from the total (TOTL) sample tends to compensate for the offsetting SY biases observed in the REC and STRA versions (small TOTL SY errors). As in the case of OTCM, the negative SX errors at 72 h are probably a result of errors in forecasting recurving storms.

Steering (CY50). In comparison to the other aids, CY50 has both the largest SX and SY errors, which gives CY50 the worst performance of any aid in terms of mean error (Fig. 5.1). SX errors increase from 131 km (36 h) to 435 km (72 h) while SY errors increase from -87 (36 h) to -323 km (72 h). These eastward and southward errors imply a slow bias for the typical motion toward the northwest. Chan (1982) found that cyclone motion in the western North Pacific region is usually faster, and to the left of the 500 mb steering flow for northwestward moving storms. By contrast, cyclone motion is usually to the right of the steering flow for westward moving storms (beta-effect). Because most cyclones have westward movement, positive SX errors exceed negative SY errors after 24 h. Also, the 500 mb steering flow does not take into account baroclinic phenomena or the beta-effect, which may influence tropical cyclone turning motion and cause significant errors in CY50 forecasts.

3. CT/AT Errors

The largest track forecast errors are associated with cyclone turning motion (Chan et al., 1980). Therefore, it is helpful to examine CT/AT components in terms of left (L), straight (C) and right (R) turning, and slow (S), central (C) and fast (F) categories relative to the storm track.

Dynamical Model (*OTCM*). The CT/AT characteristics (Fig. 5.3) with time show that the OTCM is the best aid for 48 and 72 h path prediction, and for 48 h speed prediction. The OTCM CT/AT 2-class errors are highest in the L(26%)/F(30%) terciles in the short-term (Figs. 5.4 and 5.5). During this period the OTCM correctly forecasts 65 to 70% of the right-turning or slow-moving storms, compared to only 35% of the left-turning or fast-moving cyclones. This 24 h rightward/slow bias corresponds to the small initial northeastward trend in the OTCM SX/SY profile (Fig. 5.2). The NTCM model has a similar initial bias (Chan et al., 1986). Thus, the poor skill shown by OTCM at 24 h (69 M-score) is primarily due to CT errors caused by initial positioning and/or initialization errors. After 24 h, the sharp improvement in OTCM skill is associated with a balance and reduction in these 2-class errors. The OTCM then becomes the only aid with path prediction skill in the 48 to 72 h period (58 and 61 M-scores). In addition, the OTCM is the superior aid for 48 h speed prediction (61 M-score). But a sharp degradation in speed predicton skill occurs in the 72 h projection (69 M-score), with a corresponding drop in path prediction skill (61 M-score). This degradation in OTCM skill is primarily associated with an increase in AT 2-class errors (Fig. 5.5). The 72 h CT/AT 2-class errors are highest in the R(19%)/S(25%) terciles compared to the L(8%)/S(25%) These errors are consistent with systematic errors at 72 h where a westward bias was also observed. The reason for this bias may be errors in OTCM forecasts on recurving storms, where the failure to match the right-turning motion causes negative SX errors (leftward bias in CT). A corresponding fast bias at this projection would account for the 100 km SY errors. An

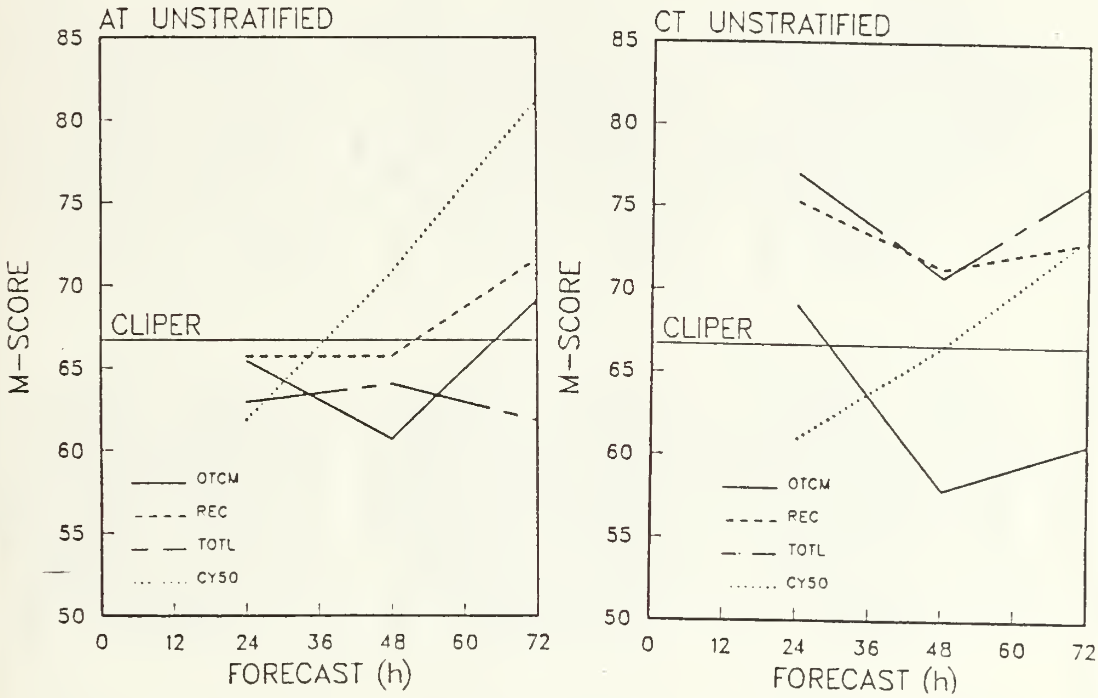

Figure 5.3 Time variations of CT and AT M-scores for the total sample of 356 objective aid forecasts.

24 h — OTCM

Best Track	%0	%1	%2
L	35.0	38.5	26.5
C	31.1	68.9	
R	65.8	21.4	12.8
Total	43.8	43.4	12.9

M Score = 69.1

24 h — REC

Best Track	%0	%1	%2
L	14.5	54.7	30.8
C	38.5	61.5	
R	53.8	43.6	2.6
Total	35.7	53.4	11.0

M Score = 75.3

24 h — TOTL

Best Track	%0	%1	%2
L	35.9	47.9	16.2
C	53.3	46.7	
R	20.5	53.8	25.6
Total	36.8	49.4	13.8

M Score = 77.0

24 h — CY50

Best Track	%0	%1	%2
L	62.4	29.1	8.5
C	47.5	52.5	
R	35.0	45.3	19.7
Total	48.3	42.4	9.3

M Score = 61.0

48 h — OTCM

Best Track	%0	%1	%2
L	64.4	23.7	11.9
C	41.3	58.7	
R	46.2	40.2	13.7
Total	50.6	41.0	8.4

M Score = 57.9

48 h — REC

Best Track	%0	%1	%2
L	25.4	44.1	30.5
C	46.3	53.7	
R	47.9	48.7	3.4
Total	39.9	48.9	11.2

M Score = 71.3

48 h — TOTL

Best Track	%0	%1	%2
L	67.8	28.8	3.4
C	56.2	43.8	
R	6.0	53.8	40.2
Total	43.5	42.1	14.3

M Score = 70.8

48 h — CY50

Best Track	%0	%1	%2
L	48.3	24.6	27.1
C	44.6	55.4	
R	42.7	48.7	8.5
Total	45.2	43.0	11.8

M Score = 66.6

72 h — OTCM

Best Track	%0	%1	%2
L	62.7	29.7	7.6
C	46.2	53.8	
R	35.3	46.2	18.5
Total	48.0	43.3	8.7

M Score = 60.7

72 h — REC

Best Track	%0	%1	%2
L	22.9	45.8	31.4
C	47.9	52.1	
R	49.6	42.0	8.4
Total	40.2	46.6	13.2

M Score = 73.0

72 h — TOTL

Best Track	%0	%1	%2
L	67.8	28.0	4.2
C	52.1	47.9	
R	4.2	47.1	48.7
Total	41.3	41.0	17.7

M Score = 76.4

72 h — CY50

Best Track	%0	%1	%2
L	40.7	28.0	31.4
C	40.3	59.7	
R	43.7	42.9	13.4
Total	41.6	43.5	14.9

M Score = 73.3

Figure 5.4 CT percentages of 0-,1- and 2-class errors (total sample) for each of the terciles of the best track distribution relative to CLIPER (L-left, C-center, R-right). M-score also indicated.

24 h — OTCM

Best Track	%0	%1	%2
S	60.2	36.4	3.4
C	37.5	62.5	
F	39.0	31.4	29.7
Total	45.5	43.5	11.0

M Score = 65.4

24 h — REC.

Best Track	%0	%1	%2
S	26.3	66.1	7.6
C	60.8	39.2	
F	36.4	50.0	13.6
Total	41.3	51.7	7.0

M Score = 65.7

24 h — TOTL

Best Track	%0	%1	%2
S	14.4	68.6	16.9
C	57.5	42.5	
F	59.3	37.3	3.4
Total	43.8	49.4	6.7

M Score = 62.9

24 h — CY50

Best Track	%0	%1	%2
S	56.8	31.4	11.9
C	43.3	56.7	
F	49.2	28.0	22.9
Total	49.7	38.8	11.5

M Score = 61.8

48 h — OTCM

Best Track	%0	%1	%2
S	42.4	41.5	16.1
C	49.6	50.4	
F	58.0	26.1	16.0
Total	50.0	39.3	10.7

M Score = 60.7

48 h — REC

Best Track	%0	%1	%2
S	19.5	55.1	25.4
C	58.0	42.0	
F	57.1	36.1	6.7
Total	44.9	44.4	10.7

M Score = 65.7

48 h — TOTL

Best Track	%0	%1	%2
S	21.2	55.1	23.7
C	46.2	53.8	
F	66.4	31.1	2.5
Total	44.7	46.6	8.7

M Score = 64.0

48 h — CY50

Best Track	%0	%1	%2
S	76.3	13.6	10.2
C	31.9	68.1	
F	29.4	31.1	39.5
Total	45.8	37.6	16.6

M Score = 70.8

72 h — OTCM

Best Track	%0	%1	%2
S	38.5	36.8	24.8
C	28.3	71.7	
F	61.3	27.7	10.9
Total	42.7	45.5	11.8

M Score = 69.1

72 h — REC

Best Track	%0	%1	%2
S	27.4	42.7	29.9
C	40.8	59.2	
F	56.3	33.6	10.1
Total	41.6	45.2	13.2

M Score = 71.6

72 h — TOTL

Best Track	%0	%1	%2
S	37.6	47.0	15.4
C	46.7	53.3	
F	52.9	39.5	7.6
Total	45.8	46.6	7.6

M Score = 61.8

72 h — CY50

Best Track	%0	%1	%2
S	81.2	6.0	12.8
C	13.3	86.7	
F	22.7	30.3	47.1
Total	38.8	41.3	19.9

M Score = 81.2

Figure 5.5 As in Fig. 5.4, except for along-track (AT) components (S-slow, C-center, F-fast relative to CLIPER).

additional contribution to the bias may be associated with the pre-processing technique causing too rapid motion of slowly-moving cyclones.

Steering (CY50). The poor performance of CY50 is a result of large CT/AT errors (Fig. 5.3). The CT 2-class errors are highest in the L(9 to 31%) terciles (Fig. 5.4) at 48 and 72 h. However, the largest CY50 errors occur in speed prediction. The slow bias observed at 24 h sharply increases in the 48 to 72 h period. The AT 2-class errors (Fig. 5.5) are highest in the fast (F) terciles, and are 23, 40 and 47% at 24, 48 and 72 h, respectively. The corresponding slow (S) 2-class errors are only 12, 10 and 13%. These errors are also consistent with the trend in the CY50 SX/SY profile (Fig. 5.2). Based on the study by Chan (1982), cyclones in the western North Pacific usually move to the left and faster than the 500 mb geostrophic steering flow. This behavior would account for the rightward/slow track bias in CY50 forecasts, and no skill in path or speed prediction after 24 h (Fig. 5.3).

Analogs (REC and TOTL). The analog CT/AT errors show that the failure of REC and TOTL is primarily in the CT component, whereas the AT component is better than CLIPER (with the exception of REC at 72 h). The CT M-scores for both analogs are in the middle and high seventies. The REC has the highest CT 2-class errors for storms in the left tercile. These high 2-class errors (31%) exist at all forecast projections, whereas the right tercile 2-class errors are in the range of 3 to 8%. This right-of-track bias is consistent with the large northward trend observed in the SX/SY errors (Fig. 5.2) for REC. Elsberry and Peak (1986) suggest that the selection of only recurving analogs results in significant forecast errors on left-turning and straight-moving storms. This may explain why the REC aid has high M-scores (73 to 75), and no skill in path prediction (Fig. 5.3).

The REC 2-class AT errors fall mainly in the slow tercile (25 to 30%) in the 48 to 72 h period. This fast bias may be a result of the faster motion present in the recurving analogs. Many cyclones are observed to undergo significant acceleration after completion of recurvature, which may contribute to the fast bias in the REC long-range forecasts.

In contrast to REC, the selection of analogs from the total sample (TOTL) results in very high 2-class CT errors for storms in the right tercile (26%, 40% and 49% at 24, 48 and 72 h, respectively). It appears that inclusion of both left- and right-turning analogs in TOTL results in a leftward track bias in CT components (Fig. 5.4) which causes errors in forecasting recurvature. However, a high percentage (over

56%) of center (C) tercile forecasts are correct. Moreover, the TOTL technique also produces skillful speed forecasts (Fig. 5.3). The TOTL aid outperforms REC, OTCM and CLIPER in 24-h speed prediction, and it is the only aid with skill at 72 h (AT M-score of 62). The AT 1- and 2-class errors are highest in the slow terciles, ranging from 15 to 24% for 2-class errors, and 47 to 70% for 1-class errors. Corresponding fast tercile errors are only 3 to 8% for 2-class errors, and 31 to 40% for 1-class errors. Thus, it appears that the utilization of the total sample of analogs results in a bias towards faster speed forecasts.

4. **Summary.**

Dynamical model (OTCM). The OTCM has the best overall performance. It is the superior aid in path prediction at 48 and 72 h, and speed prediction at 48 h. At 24 h, the OTCM shows no skill in path prediction possibly due to initial positioning and initialization errors. A peak in performance at 48 h is followed by a slight degradation in path prediction skill, and sharp reduction in speed prediction skill. This decline in forecast skill at 72 h may be a result of OTCM's long-range westward/fast bias that causes forecast positions to be ahead and left of recurving cyclone positions. Furthermore, this long-range bias may be a result of overcompensation by the OTCM preprocessing technique due to its introduction of a persistent component into the model.

Analogs (REC and TOTL). REC has a significant northward track bias that causes large errors in forecasting left-turning and straight-moving storms. This northward bias is caused by the selection of only recurving analogs (REC). In contrast, the selection of analogs from the total sample (TOTL) results in large errors due to missed recurvature forecasts (westward track bias). Thus, both analogs are unable to forecast anomalous tracks, which is consistent with findings in previous studies. However, TOTL outperforms both REC and CLIPER in speed prediction, and it is the only aid with skill in speed prediction at 72 h. The reason for TOTL speed prediction skill is probably the balance between fast and slow forecasts achieved through using the total analog sample, compared to the REC bias toward right-turning/fast-moving analogs. Therefore, the TOTL technique produces a smaller fast bias in long-range forecasts than the REC and OTCM aids.

Steering (CY50). CY50 is the best aid for 24 h path and speed prediction. However, it is the worst aid in the 48 to 72 h projection. A significant eastward/slow bias is responsible for performance degradation in the long-range projection. These biases are a result of western North Pacific tropical cyclone motion usually being faster, and to the left of 500 mb steering flow. Furthermore, without the physics of OTCM, or the climatology influence in the analog techniques, CY50 can not account for the various physical processes responsible for tropical cyclone motion (i.e., baroclinic processes or beta-effect).

The stratifications based on storm-related parameters of latitude, longitude, intensity, 12-h intensity change and size will be discussed in the following sections. Error measures will be examined to see if there are similar features regardless of storm-related classification.

B. LATITUDE

The distribution of the initial latitudes suggests the following subsamples: north zone (storm latitude at or north of 17°N), central zone (between 13°N and 17°N) and south zone (at or south of 13°N). The CLIPER MFE for 24, 48 and 72 h represent the standard of comparison for objective aid MFE (Fig. 5.6): north zone (176, 394 and 605 km), central zone (176, 386 and 618 km) and south zone (200, 466 and 707 km).

1. Dynamical Model (OTCM)

The OTCM MFE performance (Fig. 5.6) decreases with increasing latitude, as the largest OTCM forecast errors occur in the northern zone. In this zone, OTCM shows marginal skill in the 24 to 48 h period (2%) and worse than CLIPER skill (15%) at the 72 h projection. The reason for this trend in the northern zone is the high number of recurving storms that cause large forecast errors in the 48 to 72 h interval. However, 72 h performance improves with decreasing latitude. The 72 h mean error skill is 10% and 30% better than CLIPER in the central and southern zones, respectively. In the southern zone, cyclones are located farthest from the midlatitude perturbations that cause recurvature, which may be the reason why the southern zone shows the best OTCM performance.

The OTCM systematic and CT/AT errors show the initial eastward/slow and long-range westward/fast biases seen in the unstratified sample. Systematic errors (Fig. 5.7) for OTCM have their highest SY values in the northern zone. In the northern zone, the systematic error trend shows an increasing northwestward bias with time, which may be a result of recurvature errors. This trend decreases and becomes westward in the central and southern zones, where the systematic errors are quite small.

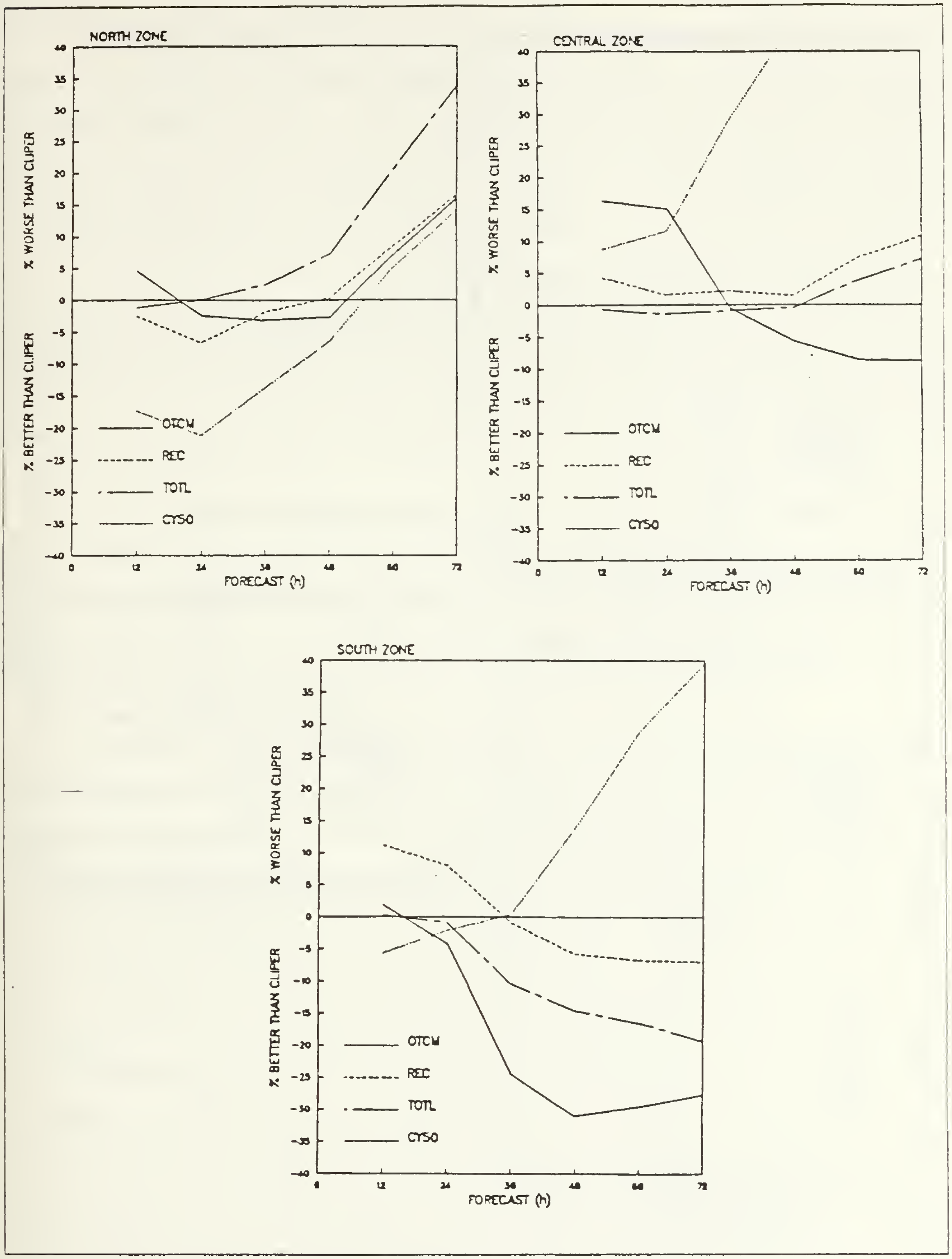

Figure 5.6 As in Fig. 5.1, except for latitude subsamples.

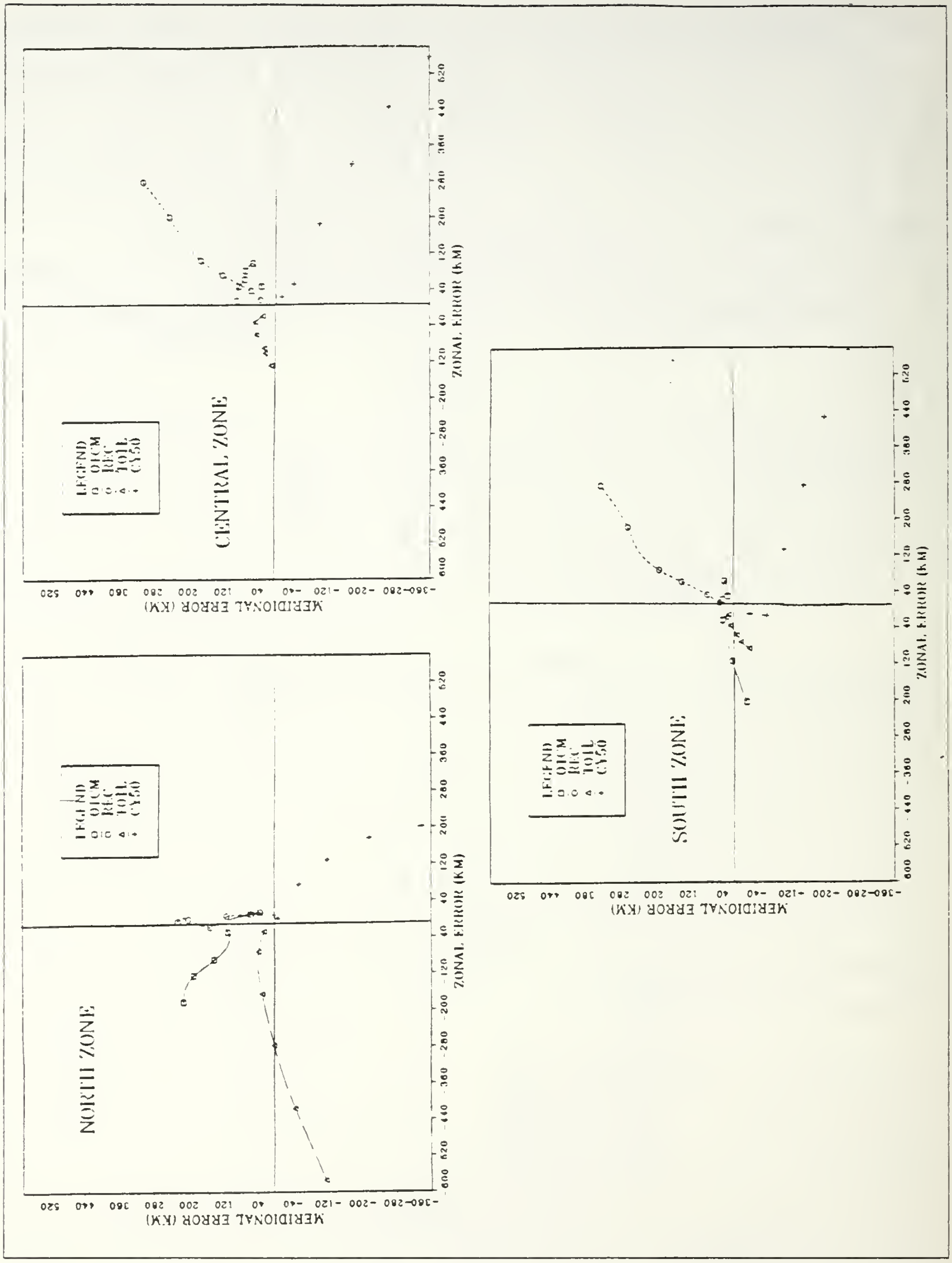

Figure 5.7 As in Fig. 5.2, except for latitude subsamples.

The CT/AT M-scores (Fig. 5.8) also decrease with decreasing latitude. In the northern zone, the OTCM shows no skill in path prediction, and no skill in speed prediction beyond 36 h. As in the unstratified sample, this is caused by a high percentage of 2-class errors (Fig. A.5) at 24 h (L, 26%; R, 23%) and 72 h (L, 24%; R, 40%). A similar trend occurs in 2-class AT errors (Fig. A.6) , with a high number of fast and slow tercile errors at 24 and 72 h (S, 38%; F, 17% at 72 h). Thus, about twice as many large errors in OTCM 72 h forecasts occur on right-turning and/or fast-moving than left-turning and/or slow moving storms in OTCM 72 h forecasts. This would correspond to the observed northwestward trend in the systematic errors (Fig. 5.7). Chan et al. (1986) found a similar trend in skill for the NTCM, and also attributed this trend to errors in predicting the recuvature process, especially in the higher latitudes (north zone).

As the numbers of right-turning and recurving storms decrease with latitude, so do the 2-class AT/CT errors. In the southern zone, there are no 2-class errors in 48 and 72 h CT components (Fig. A.1), and a reduction in AT 2-class errors (Fig. A.2) at 72 h (S, 21%; F, 6%). Therefore, the OTCM provides better path (36 to 48 M-scores) and speed prediction (55 to 63) performance in the southern zone.

2. **Analogs (REC and TOTL)**

The REC and TOTL systematic (Fig. 5.7) and CT/AT errors are consistent with the performance trends found in the unstratified sample. As in the OTCM, the analogs have increasingly lower M-scores with decreasing latitude (Fig. 5.8). The REC and TOTL aids have no skill in path prediction in the northern zone, and TOTL is the only aid with some skill in speed prediction at 72 h (65 M-score). The poor performance in AT forecasting is a result of 2-class errors in the slow terciles of 36 to 38% and 26 to 52% for REC and TOTL, respectively. In CT forecasting, REC has a large number of 1- and 2-class errors. As in the unstratified sample, the 2-class errors for REC fall mainly in the left tercile (Fig. A.5). These results imply that the REC forecasts in the northern zone, which includes a large number of recurving cases, are still likely to be east, and ahead of the storm tracks. In contrast to REC, the TOTL aid has extremely high 2-class CT errors that reach a total of 32 % at 72 h, with the majority falling in the right tercile (L, 2%; R, 93%). Thus, the TOTL correctly forecasts 86% of the left-turning storms and 0% of the right-turning storms in the northern zone. These results are consistent with the systematic error results, where the largest TOTL westward bias occurs in the northern zone (Fig. 5.7).

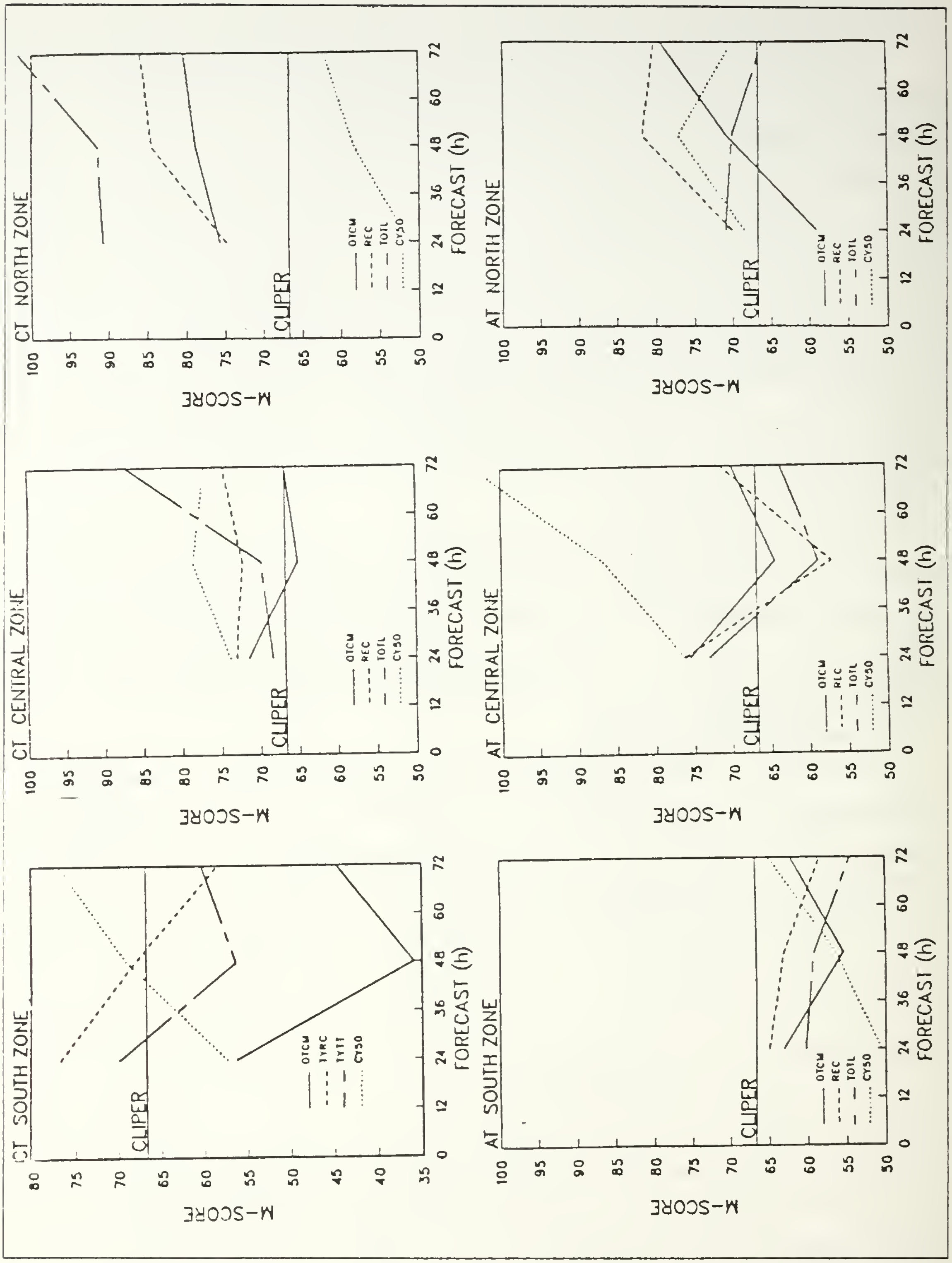

Figure 5.8 As in Fig. 5.3, except for latitude subsamples.

As CT/AT errors decrease with latitude, a reduction is seen in CT M-scores from 80 to 100 in the northern zone to 57 - 60 in the southern zone. The best analog aid performance occurs in the southern zone. Both analogs have path prediction skill at 72 h. Skill in speed prediction is demonstrated at all forecast periods, with TOTL outperforming all aids by 72 h (Fig. 5.8).

3. **Steering (CY50)**

The CY50 aid mean error performance (Fig. 5.6) shows an opposing trend in comparison to other aids by showing improvement in skill with increasing latitude. In the southern zone, CY50 shows skill only at 24 h (marginal), whereas no skill is demonstrated in the central zone. In the northern zone CY50 is 20% and 10% better than CLIPER at 24 and 48 h, repsectively. No skill is evident in the north zone 72 h forecasts.

As in the unstratified sample, CY50 systematic (Fig. 5.7) and CT/AT errors show a large southeastward (rightward)/slow bias in all latitude zones. Although CY50 is the only aid with path prediction skill in the northern zone (Fig. 5.8), a sharp decline in the CT/AT M-scores with time occurs in all latitude subsamples. In the central zone, 1- and 2-class errors increase in all tercile categories, which results in a no skill performance in path and speed prediction (Figs. A.3 and A.4). Due to the persistent nature of storms in the southern zone, CY50 has its best AT M-score (Fig. 5.8) performance (50 at 24 h, and 65 at 72 h), while short-term skill is demonstrated in path prediction (57 M-score at 24 h). The rightward/slow bias seen in the central and northern subsamples is still present in the southern zone and causes a sharp decline in long-range path and speed prediction performance.

4. **Guidance Summary**

Consistent with previous studies (Jarrell et al., 1978; Neumann and Pelissier, 1981b; and Thompson et al., 1981), the largest forecast errors are found in the higher latitudes due to recurving storms. The long-range westward biases of OTCM and TOTL, and the northward bias of REC, are responsible for these recurvature errors in the northern zone. Thus, the only aid to have path prediction skill in the northern zone is the CY50. The CY50 steering aid does well in path prediction skill in the northern zone because the steering flow usually takes on an increasingly westerly direction as the storm moves north of the subtropical ridge. However, the slow bias in CY50 gives it the worse long-range speed performance of any objective aid. Improvement in OTCM and analog aid performance is observed with decreasing latitude. In the central and southern zones, the OTCM and TOTL become the best aids for long-range path and speed prediction, respectively, while CY50 is the worse overall performing aid. The following guidance is provided for the latitude sample:

1) *North Zone (latitude > 17°N). Path prediction-* CY50 at 24, 48 and 72 h. *Speed prediction-* OTCM at 24 h, CLIPER at 48 h, and TOTL at 72 h;

2) *Central Zone (between 13°N and 17°N). Path prediction-* CLIPER at 24 h and OTCM at 48 and 72 h. *Speed prediction-* CLIPER at 24 h, REC at 48 h and TOTL at 72 h; and

3) *South Zone (< 13°N). Path prediction-* OTCM at 24, 48 and 72 h. *Speed prediction-* CY50 at 24 h, OTCM at 48 h and TOTL at 72 h.

C. LONGITUDE

Based on the initial longitude, the objective aid forecasts are divided into three subsamples: western area (longitude at or west of 129°E), middle area (between 129° and 140°E) and eastern area (at or east of 140°E). The CLIPER MFE for 24, 48 and 72 h are the standard of comparison (Fig. 5.9): western area (147, 352 and 579 km), middle area (188, 395 and 596 km) and eastern area (220, 499 and 763 km).

1. Dynamical Model (OTCM)

The MFE variation with longitude (Fig. 5.9) indicates that the OTCM aid has the worst and best performances in the western and eastern areas, respectively. Although the western area is relatively data rich compared to the other areas, it is also the most complex to forecast due to the presence of large land masses (i.e., the Philippines and Taiwan). Unless they originated in the South China Sea, cyclones that reach this area are well-developed systems that have failed to recurve.

The middle area has both westward-moving and recurving storms. The OTCM MFE skill in this area is 15% and 10% better than CLIPER at 48 and 72 h, respectively. However, the best OTCM peformance occurs in the eastern area where the 72 h skill remains at 15% better than CLIPER. The reasons for the differences between middle and eastern area may be: 1) the greater variability of cyclone motion in the middle area; and 2) the measure of skill (CLIPER) changes so dramatically that OTCM may not actually be that much better in the eastern zone compared to the middle zone.

The OTCM systematic errors (Fig. 5.10) and CT/AT errors (Fig. 5.11) have the same long-range westward/fast bias seen in previous samples. Consistent with mean error skill, the OTCM has improved CT/AT M-score variations with longitude. In the western area, a large number of 2-class errors (Fig. A.7) occur at 72 h (L, 19%; R,

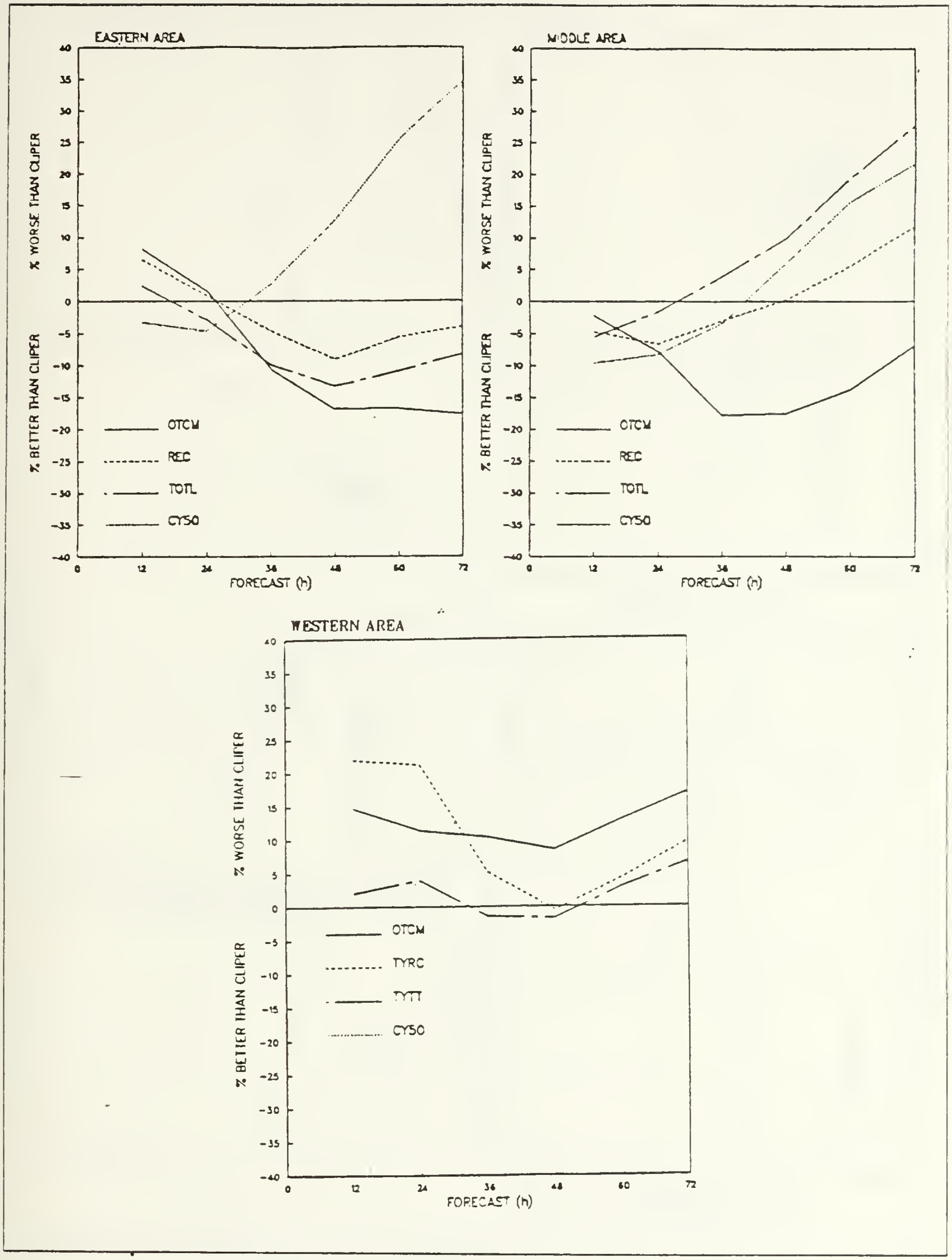

Figure 5.9 As in Fig. 5.1, except for longitude subsamples.

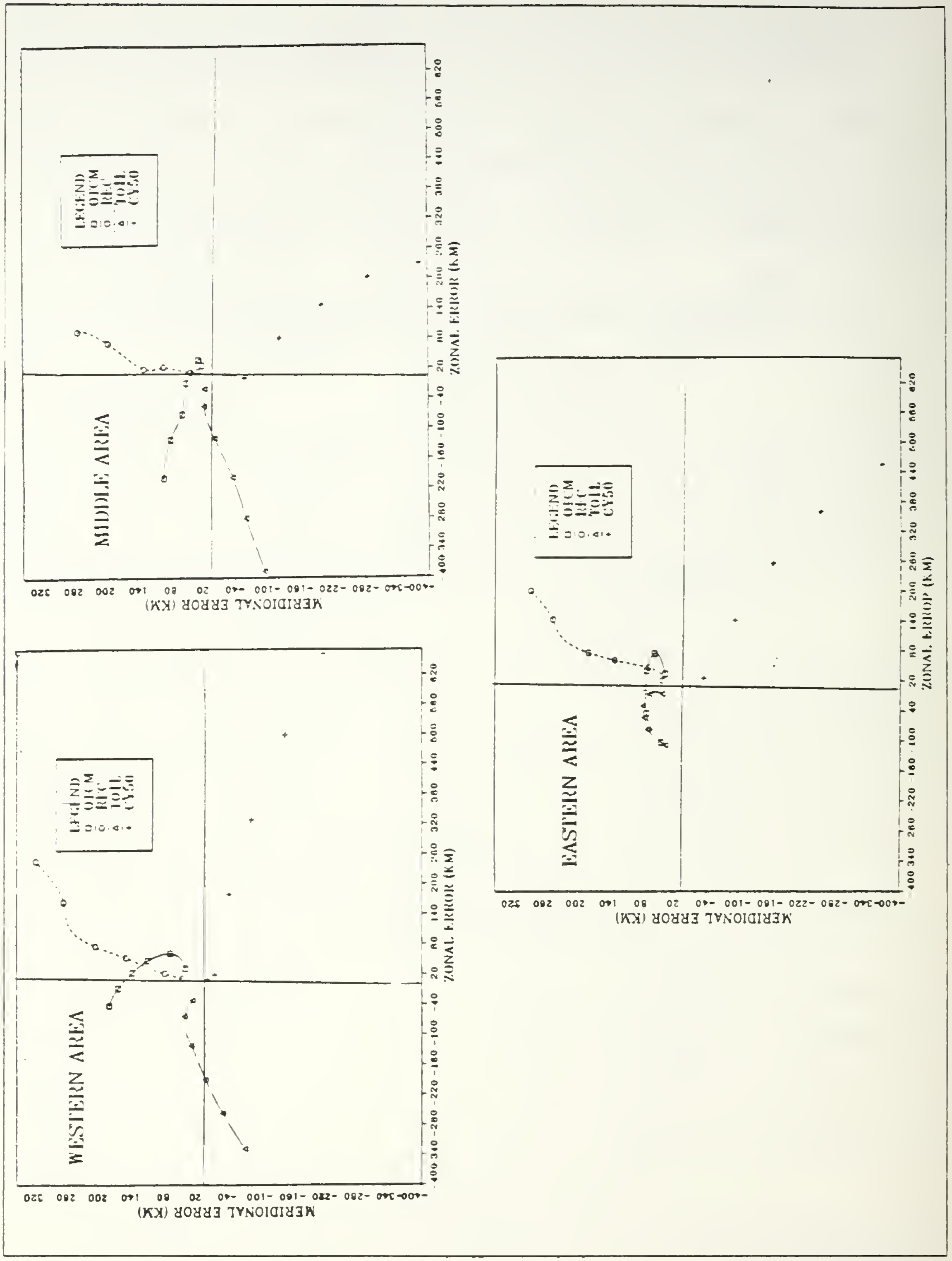

Figure 5.10 As in Fig. 5.2, except for longitude subsamples.

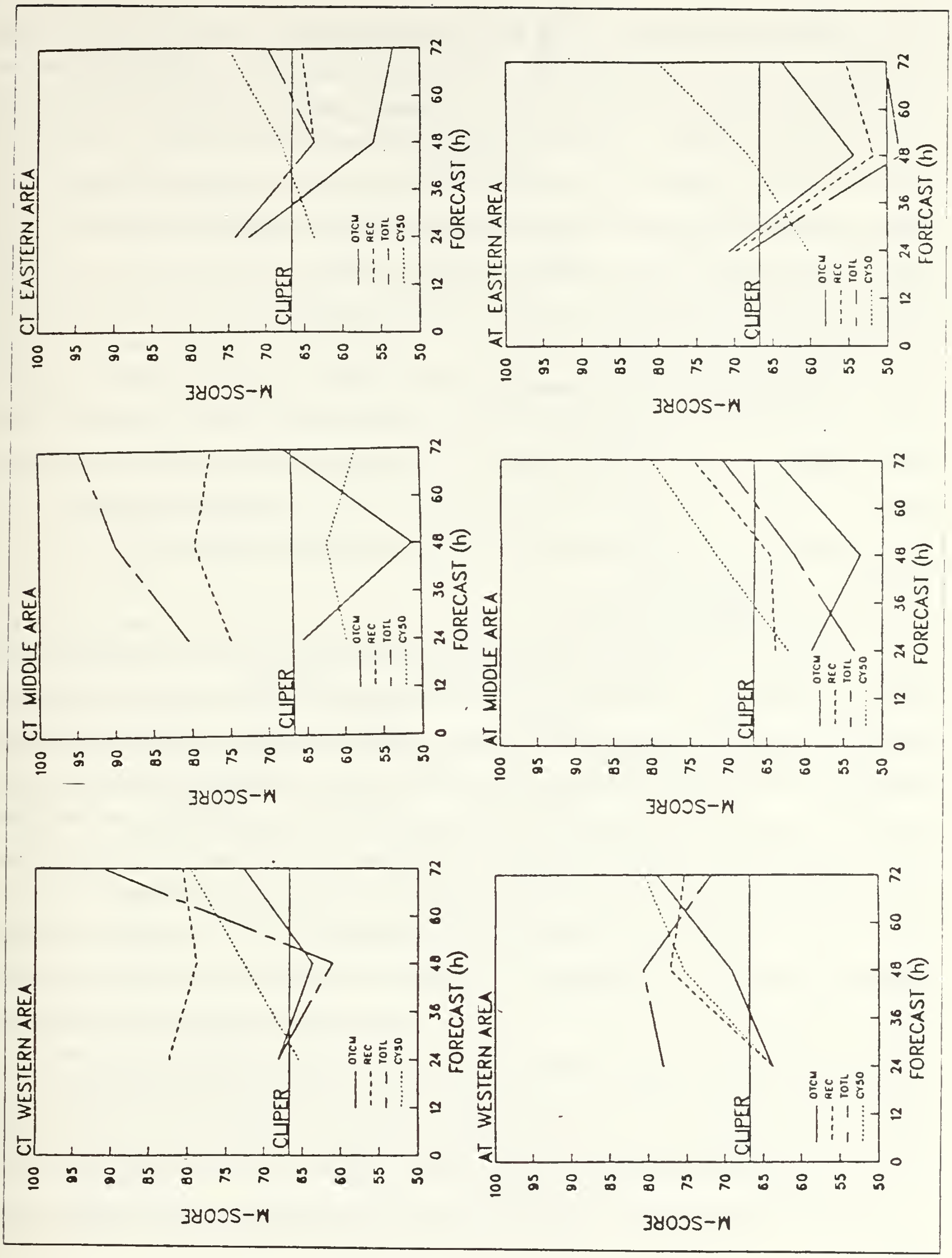

Figure 5.11 As in Fig. 5.3, except for longitude subsamples.

24%). However, these 2-class errors decrease in the eastern area. In the middle area, the OTCM has the best 48 h path skill performance, but shows no skill at 72 h because of recurvature errors (L, 10%; R, 35%). In speed prediction, the OTCM shows skill at all forecast projections. The overall best OTCM performance occurs in the eastern area where most cyclones are westward movers (anomalous tracks do occur at the higher latitudes in this area). The OTCM path prediction skill (Fig. A.11) shows no decline at 72 h due to a low number of 2-class errors (L, 0%; R, 5%). The AT prediction skill for the OTCM declines at 72 h, although the 2-class errors (Fig. A.12) are reduced (S, 18%; F, 3%).

In contrast to the above findings for the OTCM, Chan et al. (1986) found the lowest NTCM CT M-scores in the western area subsample. However, they did find a similar leftward bias in the NTCM 48 to 72 h forecasts which they attributed to the failure to predict recurvature. Furthermore, the NTCM had a rightward bias at 24 h only in the eastern area, whereas the OTCM has a consistent rightward bias at 24 h in all samples discussed thus far.

2. Analogs (REC and TOTL)

Unlike the OTCM model, the analogs do not show any long-range skill in the middle area (Fig. 5.9). The reason for this behavior may be their respective biases, or the dramatic change in the measure of skill (CLIPER) between longitude subsamples. The mixture of westward-moving and recurving storms in the middle area can cause large REC and TOTL forecast errors as a result of their northward and westward biases, respectively. However, the analog aids show improvement (5 to 10% better than CLIPER) in the eastern area where cyclone motion is more persistent.

CT/AT M-score variations with longitude show poor analog aid path prediction skill in all areas, and superior speed prediction skill in the eastern area (Fig. 5.11). In the western area, CLIPER outperforms the analogs at 24 and 72 h, whereas TOTL has the best CT skill of any aid at 48 h (60 M-score). REC and TOTL show no skill in speed prediction after 24 h (64 M-score at 24 h). The 72 h rightward bias of REC (L, 56%; R, 13%) and leftward bias of TOTL (L, 3%; R, 79%) cause large errors on failed-recurving and recurving cyclones, respectively. Furthermore, the fast bias exhibited by both aids results in no skill in the long-range speed forecasts (Fig. A.8).

In the eastern area, the persistent cyclone motion results in path prediction skill at 48 h (64 M-scores) and 72 h (REC M-score of 64). Both analog aids show superior long-range skill in speed prediction, with TOTL as the best aid at 48 and 72 h (50 M-scores). During this period, REC and TOTL AT 1-class errors are highest in the slow tercile (REC, 58 - 92%; TOTL, 53 - 76%). The corresponding range of AT 2-class errors is only 0.9 to 5% for both aids (Fig. A.12).

3. Steering (CY50)

The CY50 aid has the worst mean error skill of any aid (Fig. 5.9). The only skill shown by this aid in the longitude sample occurs in the middle and eastern area 24 h forecast periods (10 and 5% better than CLIPER, respectively). The CY50 has no skill in speed prediction beyond 24 h in any longitude subsample (Fig. 5.11). Futhermore, CY50 has no path prediction skill beyond 24 h in the western and eastern areas. However, CY50 performs well in path prediction in the middle area. In the middle area, CY50 outperforms all aids in CT skill at 24 and 72 h (60 M-scores).

4. Guidance summary

CLIPER outperforms all objective aids in the western area. In the western area, the benefit of data availability appears to be outweighed by additional complexity such as cyclone interaction with terrain. However, objective aid performance improves with increasing east longitude. In the middle and eastern areas, the OTCM has the best performance due to small systematic errors, and skill in both path and speed prediction. The REC and TOTL analogs also improve with increasing east longitude. In the middle and eastern area, the analogs have the best skill in speed prediction. However, no path prediction skill is evident in the middle area. The middle area has both recurving and westward-moving storms. The northeastward and westward biases of REC and TOTL are responsible for large errors on westward moving and recurving storms, respectively. In the eastern area, the persistence in tropical cyclone motion reduces errors as a result of individual aid biases. The following forecasting guidance is provided for the longitude stratification:

1) *Western area (longitude < 129°E). Path prediction-* CY50 at 24 h, TOTL at 48 h and CLIPER at 72 h. *Speed prediction-* OTCM, REC or CY50 at 24 h and CLIPER at 48 and 72 h;

2) *Middle area (between 129°E and 140°E). Path prediction-* CY50 at 24 and 72 h and OTCM at 48 h. *Speed prediction-* TOTL at 24 h and OTCM at 48 and 72 h; and

3) *Eastern area (> 140°E). Path prediction-* CY50 at 24 h and OTCM at 48 and 72 h. *Speed prediction-* CY50 at 24 h and TOTL at 48 and 72 h.

D. INTENSITY

The intensity is the estimated maximum sustained wind at warning time. The distribution of the sample based on initial intensity gives the following subsamples: Weak (< 55 kt), moderate (between 55 kt and 90 kt) and intense (> 90 kt). The CLIPER MFE standard of comparison for 24, 48 and 72 h objective aid MFE (Fig. 5.12) is as follows: weak (210, 450 and 666 km), moderate (184, 415 and 643 km) and intense (159, 381 and 616 km).

1. Dynamical Model (OTCM)

The mean errors as a function of intensity (Fig. 5.12) indicate that the OTCM performs best on cyclones of moderate intensity, and is less accurate for intense storms. No skill is evident in the short-term OTCM forecasts of weak and intense cyclones, although the weak subsample displays the best 72-h performance. These errors in the weak intensity subsample are probably a result of the difficulty in estimating the initial position of ill-defined, weak cyclones. Furthermore, these errors may be a result of the deep tropospheric bogus storm in the OTCM for all cases regardless of actual intensity.

The systematic errors (Fig. 5.13) are smallest in the moderate subsample, which accounts for the good performance of the OTCM in this category. The weak subsample has the largest initial SX/SY errors, which is consistent with errors caused by initial positioning, whereas a long-range northwestward bias in the intense category is indicative of recurvature forecast errors. The NTCM (Chan et al., 1986) also shows a growing westward bias for intense storms. This NTCM trend was similarly attributed to the failure of the NTCM to predict recurvature of the intense cyclones.

The CT/AT error components (Fig. 5.14) also show that the best OTCM performance occurs with cyclones of moderate intensity. For these cyclones, OTCM is superior to the other aids in path prediction, and demonstrates skill in speed prediction in all forecast intervals. However, no significant skill is shown in speed prediction for weak cyclones. The 2-class AT errors (Fig. A.14) suggest a large slow bias (F, 35%) at 24 and 48 h , while 1- and 2-class errors at 72 h suggest a fast bias. As discussed in the previous stratifications, this speed prediction trend causes OTCM forecast positions to be ahead of actual storm track. However, the mean error performance (Fig. 5.14) in the weak intensity subsample (10% better than CLIPER) indicates that these speed errors do not offset completely the CT prediction skill.

In the intense subsample, the OTCM has path prediction skill only at 48 h, whereas speed prediction skill exists at all forecast periods. In this subsample, the 1-

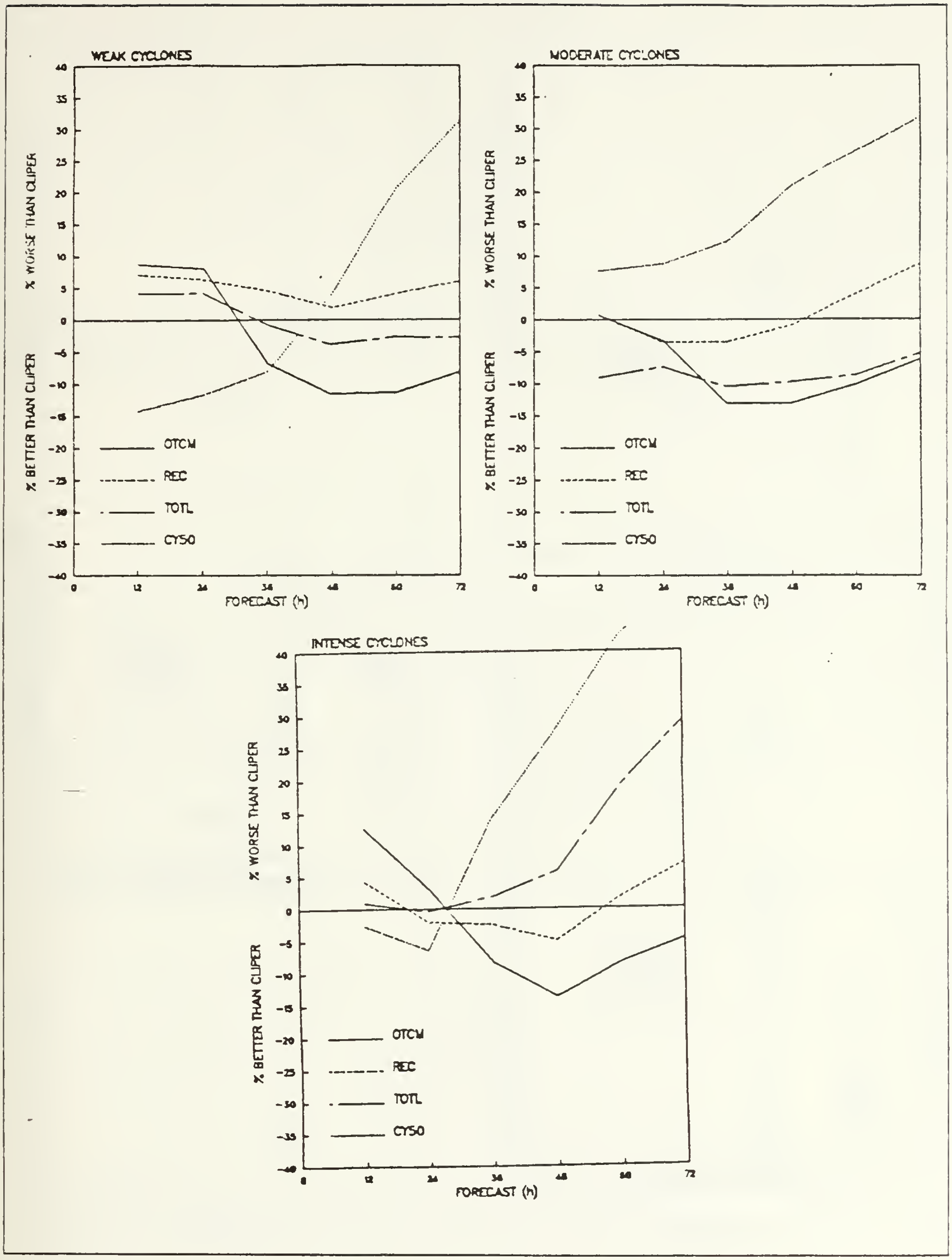

Figure 5.12 As in Fig. 5.1, except for intensity subsample.

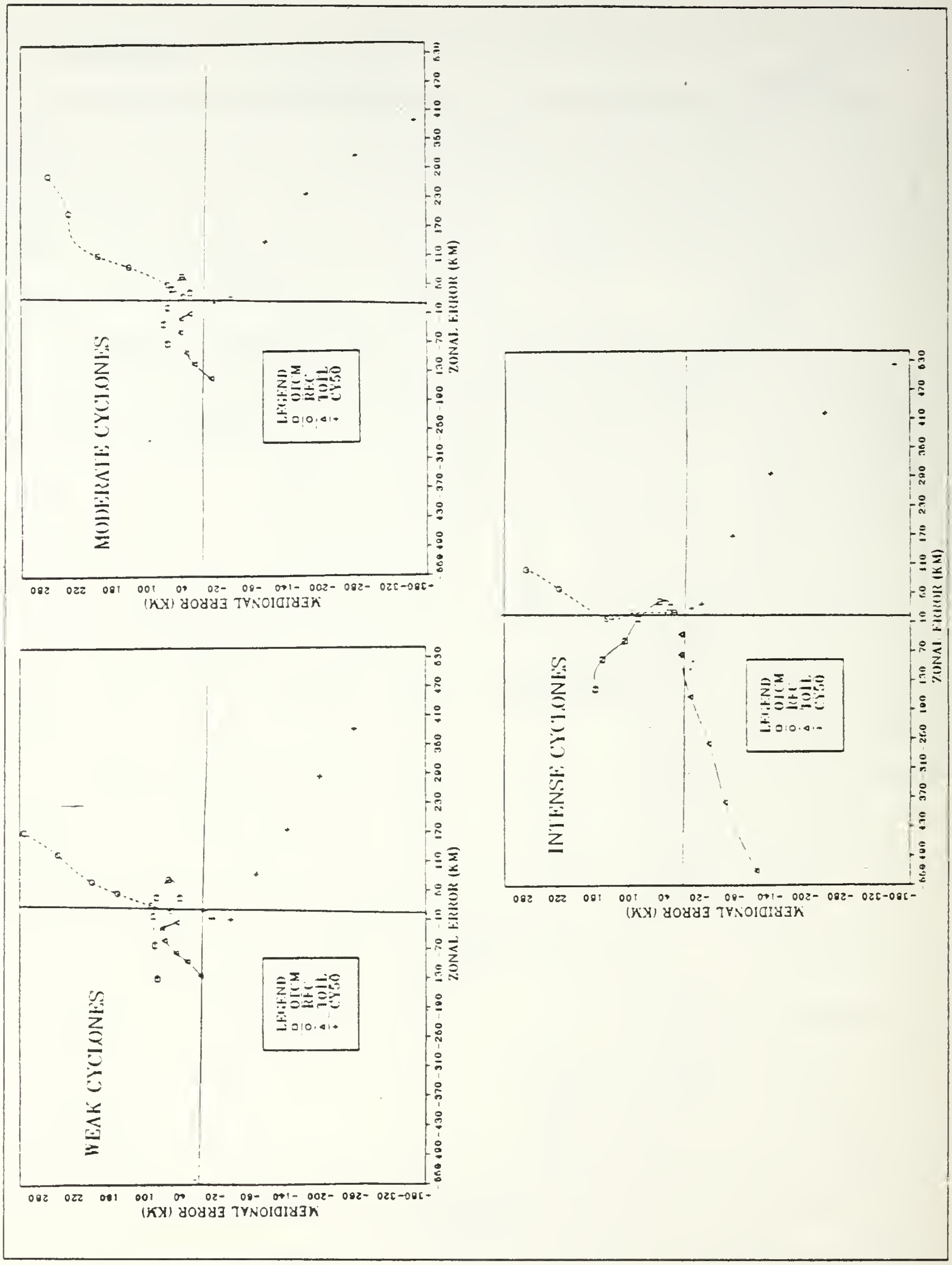

Figure 5.13 As in Fig. 5.2, except for intensity subsamples.

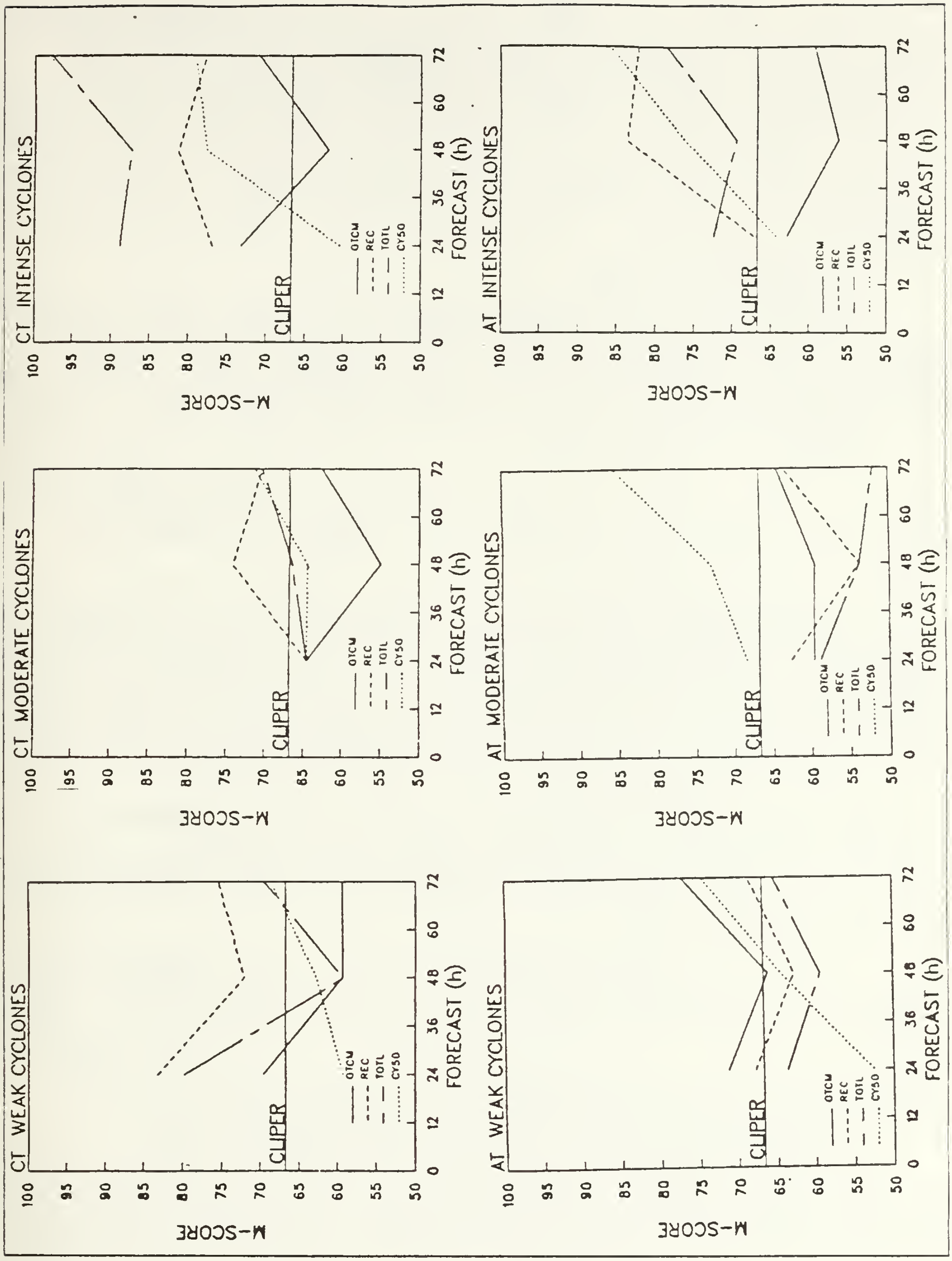

Figure 5.14 As in Fig. 5.3, except for intensity subsamples.

and 2-class AT errors at 72 h show a leftward track bias. A similar, but smaller leftward bias is also present in the moderate subsample (mostly 1-class errors). The best performance for the NTCM also occurs in the medium intensity subsample (Chan et al., 1986). The NTCM CT errors are biased to the right of the best track for the weak group, evenly distributed for the medium group, and left-of-track for the intense subsample. In all cases, the OTCM has an initial right-of-track bias followed by a long-range left-of-track bias.

2. Analogs (REC and TOTL)

The REC aid shows no MFE skill (Fig. 5.12) in the weak intensity subsample. However, the REC performance improves with increasing cyclone intensity. For moderate intensity cyclones, REC has marginal short-term skill, and no long-range skill. Although still marginal, the REC shows some improvement (1 to 2%) in 48 h forecasts of intense cyclones. This small improvement in REC skill with increasing cyclone intensity may be due to an increase in the number of recurving cyclones with intensity.

The REC systematic (Fig. 5.13) and CT/AT error trends are consistent with those in previous samples (northeastward bias). The CT/AT M-scores for REC (Fig. 5.14) indicate no skill in path prediction for weak and intense cyclones, and path prediction skill only at 24 h for moderate intensity cyclones. As in previous samples, REC has a high percentage of 2-class errors in the left (L) tercile (Fig. A.17). In the AT components, the REC aid shows skill in the weak and moderate intensity subsamples, with the best performance in the moderate subsample. The intense category has no skill in speed prediction due to a high percentage of 2-class errors in the slow (S) tercile (Fig. A.18).

In contrast to REC, TOTL performs best (Fig. 5.12) on moderate intensity cyclones, and has less skill on intense cyclones. As in the previous TOTL samples, systematic errors (Fig. 5.13) show a westward bias. In the intensity sample, this westward bias increases with increasing cyclone intensity and may be indicative of an increase in the number of recurving storms with increasing storm intensity.

The TOTL CT/AT M-scores (Fig. 5.14) show no speed or path prediction skill for intense cyclones. The 2-class CT errors (Fig. A.17) are consistent with systematic errors (Fig. 5.13) in that they show a large left-of-track (westward) bias in the intense cyclone subsample at all forecast periods. A corresponding fast bias is also indicated by AT 2-class errors (Fig. A.18).

3. **Steering (CY50)**

The CY50 aid has no long-range skill in the intensity sample (Fig. 5.12). However, some short-term skill is shown in the weak and intense subsamples. As in previous samples, systematic errors (Fig. 5.13) show a large southeastward trend. The CT/AT errors also indicate that CY50 has an increasing right-of-track bias with increasing cyclone intensity. This is consistent with a study by Chan (1982) in which cyclone movement was increasingly to the left of the 500 mb steering flow with increasing cyclone intensity. Furthermore, cyclone speed was usually faster than the 500 mb flow. The lowest number of 2-class CT/AT errors are in the weak intensity subsample where CY50 has short-term CT and AT skill (Figs. A.17 and A.18). However, the CY50 rightward/slow track bias makes it the worst overall aid in the intensity stratification.

4. **Guidance Summary**

The OTCM aid performs well in predicting the turning motion of weak cyclones. However, the OTCM long-range fast bias causes errors in speed prediction. Thus, the OTCM can only demonstrate AT skill at 48 h in the weak subsample. The best OTCM performance occurs in the medium intensity subsample where the aid has speed and path prediction skill at all forecast periods. In the intense subsample, OTCM has path prediction skill only at 48 h as a result of a long-range leftward track bias. —

The REC and TOTL analogs have superior skill in speed prediction in the weak and medium intensity subsamples, but no path prediction skill (with the exception of TOTL at 48 h). The northeastward bias in REC is responsible for errors in the weak and medium subsamples, whereas a westward bias in TOTL causes similar results. For intense storms, the analog aids show no skill in either path or speed prediction. The fast biases in both aids appear responsible for their lack of AT skill for intense cyclones.

The CY50 aid has no speed or path prediction skill beyond 24 h, except in the medium subsample (path skill at 48 h), because of its large southeastward bias. CY50 forecasts are usually slower and right of actual storm position for most categories of cyclone motion. The slow bias, rather than the rightward bias, is responsible for poor CY50 performance.

1) *Weak intensity (< 55 kt). Path prediction-* CY50 at 24 h, OTCM or TOTL at 48 h and OTCM at 72 h. *Speed prediction-* CY50 at 24 h and TOTL at 48 and 72 h;

2) *Moderate intensity (between 55 and 90 kt). Path prediction-* OTCM, REC, TOTL or CY50 at 24 h and OTCM at 48 and 72 h. *Speed prediction-* TOTL at 24 and 72 h, and REC and TOTL at 48 h; and

3) *Intense (> 90 kt). Path prediction-* CY50 at 24 h, OTCM at 48 h and CLIPER at 72 h. *Speed prediction-* OTCM at 24, 48 and 72 h.

E. 12-HOUR INTENSITY CHANGE

The 12-h intensity changes (IC) are divided into the following subsamples: weakening (IC < 0 kt), intensifying (between 0 and 5 kt) and rapidly intensifying (IC > 5 kt). The CLIPER MFE for 24, 48 and 72 h represent the standard of comparison for objective aid MFE (Fig. 5.15): weakening (160, 390 and 675 km), intensifying (197, 443 and 640 km) and rapidly intensifying (179, 411 and 647 km).

1. Dynamical Model (OTCM)

The OTCM model worst and best mean error performances (Fig. 5.15) occur in the weakening and rapidly intensifying subsamples, respectively. The OTCM has no skill in the weakening group. Storms generally intensify rapidly at relatively low latitudes and weaken as they move to high latitudes. Furthermore, weakening storms are either approaching landfall or undergoing upper-level shear and recurvature. In the intensifying and rapidly intensifying subsamples, the OTCM has peaks in skill relative to CLIPER at 48 h of 15 and 18%, respectively, while the 72-h skill is 10%. The improved performance for intensifying and rapidly intensifying cyclones may be a result of their better definition, thereby reducing initial positioning errors.

The OTCM systematic (Fig. 5.16) and CT/AT errors indicate the presence of a westward bias as in the distribution of previous samples. Similar to the NTCM performance (Chan et al., 1986), the best OTCM performance is on rapidly intensifying storms (Fig. 5.17). In the CT components, the best OTCM performance is on intensifying storms. As in the NTCM, the worst OTCM CT forecasts are associated with weakening cyclones. In the weakening subsample, there is no OTCM CT skill beyond 24 h (Fig. 5.17). Furthermore, both models have a high percentage of 2-class CT errors for right-turning storms (Figs. A.19, A.21 and A.23). Moreover, Chan et al. (1986) found the worst NTCM forecasts for the AT component in the weakening category, whereas the OTCM AT skill occurs at 48 h for weakening storms and 24 and 48 for intensifying storms. For these weakening storms, the OTCM correctly forecasts 57 to 74% of the slow moving storms compared to only 34 to 48% for fast moving storms. In previous stratifications, the OTCM has a long-range fast bias that reduces skill in AT prediction at 72 h. In contrast to the NTCM, which has a slow bias in all intensity change subsamples, the OTCM has some AT skill, especially in the rapidly intensifying sample as a result of a reduction in 1- and 2- class errors. The 2-class AT errors in the slow tercile are primarily responsible for this long-range fast bias (S, 27%; F,16%) in the intensifying sample.

In the rapidly intensifying sample, small and equally balanced right and left tercile 2-class errors are the reason for the consistent OTCM long-range path prediction performance (61 M-score at 48 and 72 h). In this sample, the OTCM characteristic "V" shape in CT prediction skill at 24, 48 and 72 h is due to a short-range slow bias (2-class errors of S, 2%; F, 29% at 24 h) and the long-range fast bias (2-class errors of S, 31%; F, 9%). However, speed prediction skill is shown in all forecast periods.

2. Analogs (REC and TOTL)

As in the OTCM, the analog aids have no mean error skill in the weakening group and their performance improves in the intensifying subsample. In the intensifying group, TOTL outperforms (10 % better than CLIPER) REC (3 %). However, no long-range skill in CT or AT is demonstrated by either aid for intensifying storms. In the rapidly intensifying group, REC and TOTL are only 4 % better than CLIPER in the 36 to 48 h period, and have no skill at 72 h.

—The REC and TOTL systematic (Fig. 5.16) and CT/AT error trends are similar to those seen previously in other stratifications. In all cases, the analog aids show no long-range path prediction skill (Fig. 5.17). A similar performance occurs in speed prediction. The only AT skill for weakening cyclones is seen in the TOTL aid.

3. Steering (CY50)

The only demonstrated CY50 skill is in the 24 h period of all subsamples (Fig. 5.15). The CY50 systematic errors (Fig. 5.16) again suggest that the characteristic southeastward bias in CY50 is responsible for the poor mean error performance. In the CT components, the CY50 is the best aid for weakening cyclones, and also performs well in the intensifying subsample (Fig. 5.17). The CY50 has no CT skill for rapidly intensifying storms. In all cases, CY50 has a steady decline in CT skill throughout the forecast period. However, CT/AT M-scores (Fig. 5.17) suggest that errors in the speed forecast (particularly the slow bias) are responsible for the overall poor mean error performance.

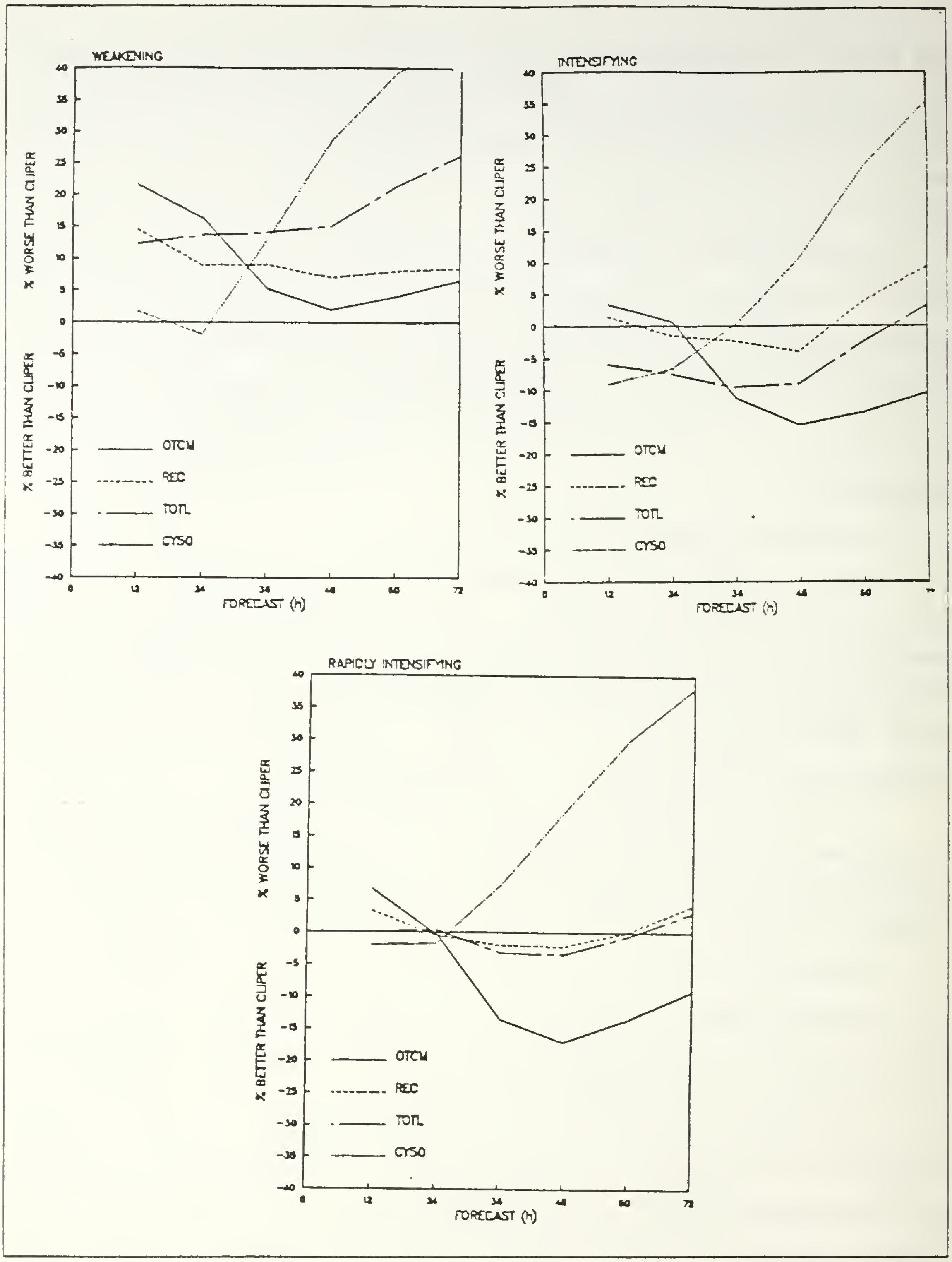

Figure 5.15 As in Fig. 5.1, except for 12-h intensity change subsamples.

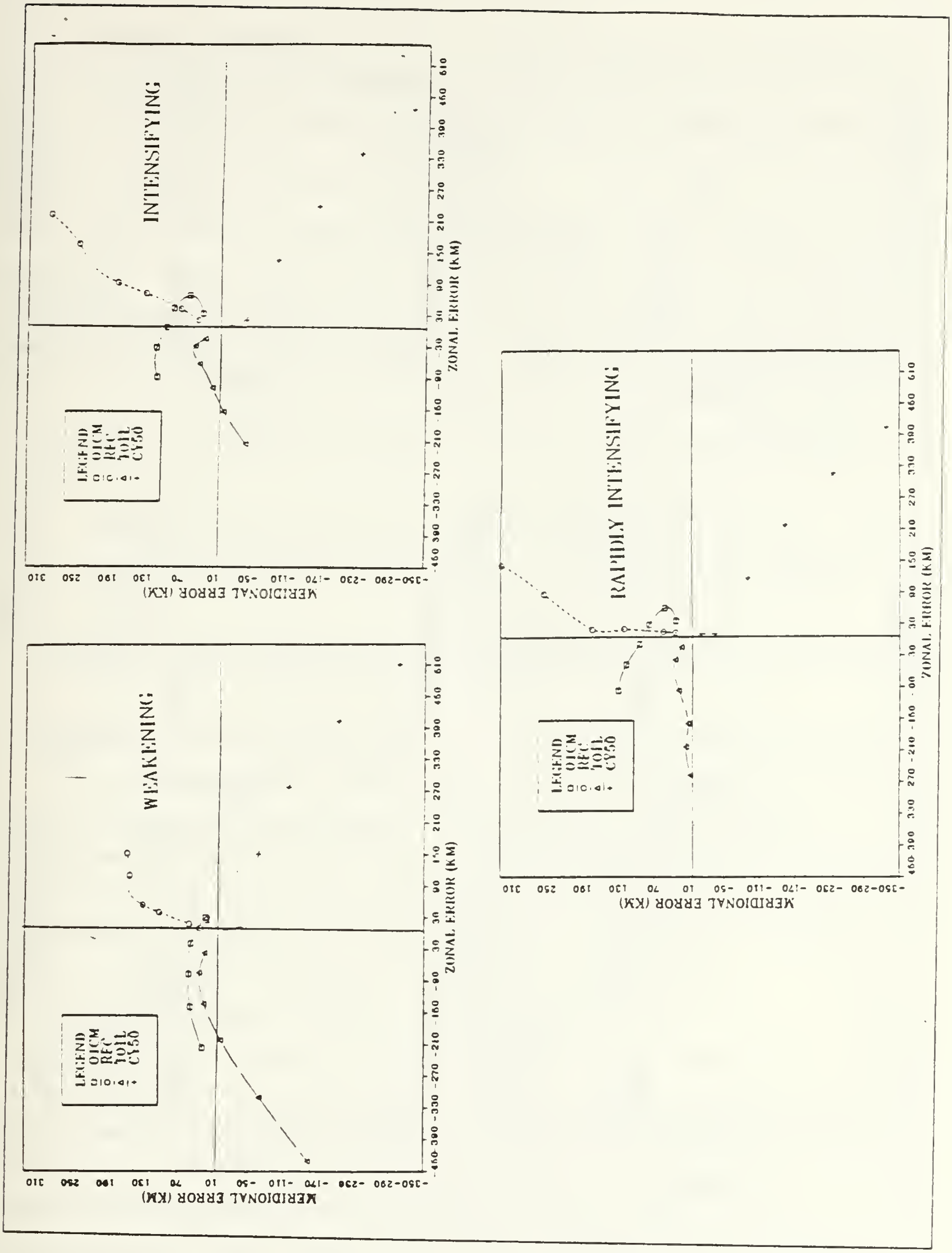

Figure 5.16 As in Fig. 5.2, except for 12-h intensity change subsamples.

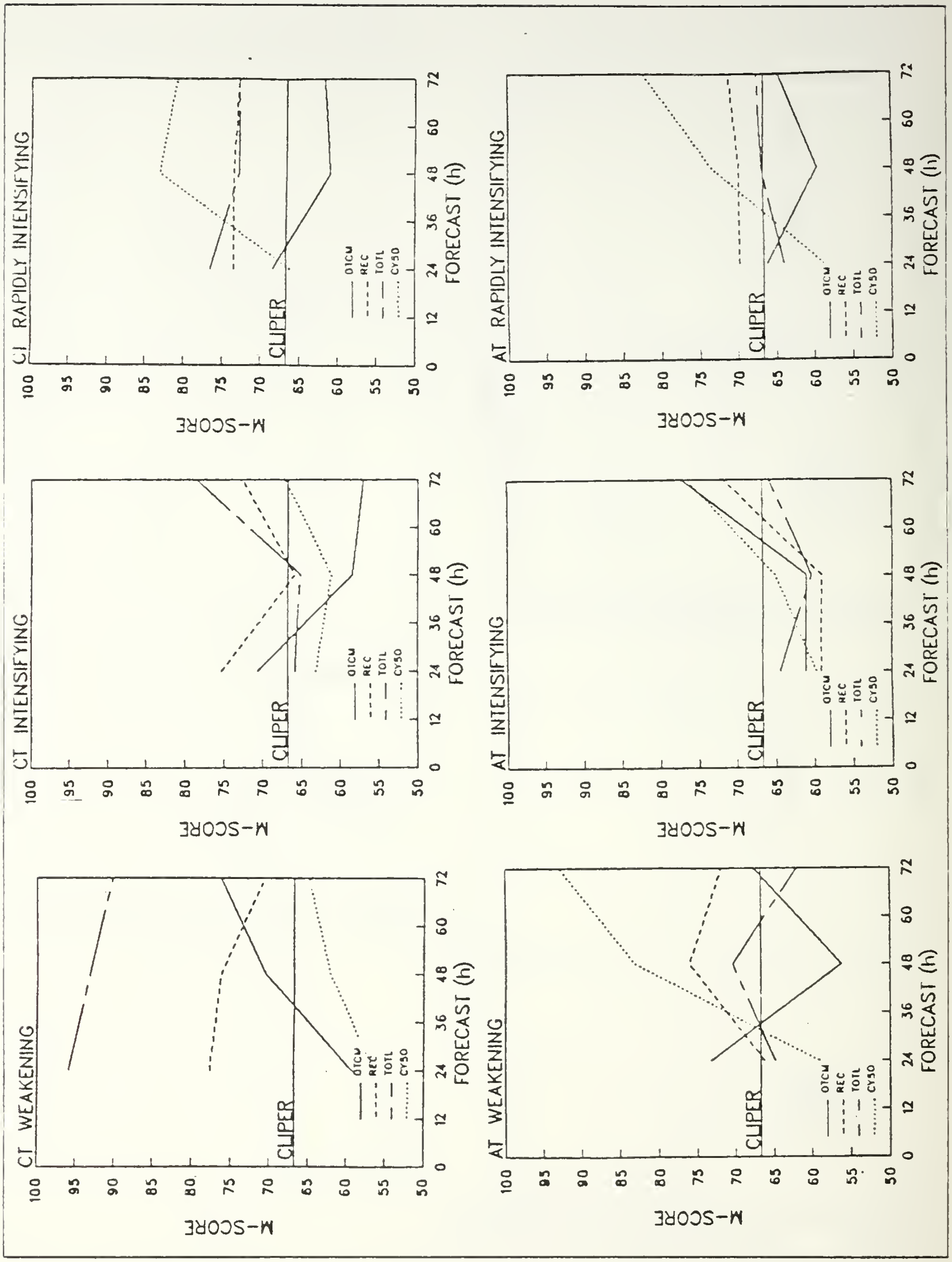

Figure 5.17 As in Fig. 5.3, except for 12-h intensity change subsamples.

4. **Guidance Summary**

The best OTCM performance is on intensifying and rapidly intensifying storms, whereas the worst performance is associated with weakening cyclones. The weakening storms usually occur at relatively high latitudes, and are generally undergoing landfall or recurvature.

The analog aids appear insensitive to the 12-h intensity change. Both REC and TOTL perform poorly in all cases due to their respective northward/fast and westward/fast biases. Finally, the CY50 aid is the only aid with CT skill in the weakening subsample. The CY50 also has CT skill for intensifying storms, but has no skill for rapidly intensifying storms. The rightward/slow bias in CY50 is responsible for the decline in CT skill with time and the lack of AT skill in all intensity change subsamples.

1) *Weakening cyclones (12-h IC < 0 kt). Path prediction-* CY50 at 24, 48 and 72 h. *Speed prediction-* CY50 at 24 h, OTCM at 48 h and TOTL at 72 h;

2) *Intensifying (12-h IC between 0 and 5 kt). Path Prediction-* CY50 at 24 h and OTCM at 48 and 72 h. *Speed prediction-* REC at 24 and 48 h and TOTL at 72 h; and

3) *Rapidly intensifying (12-h IC > 0). Path prediction-* CY50 at 24 h and OTCM at 48 and 72 h. *Speed prediction-* CY50 at 24 h and OTCM at 48 and 72 h.

F. SIZE

The radius (R) of 15 m/s winds is one measure of the size of a tropical cyclone. These storm sizes can be divided into three subsamples: small cyclones (R < 135 n mi), medium cyclones (between 135 and 220 n mi) and large cyclones (R > 220 n mi). The CLIPER MFE for 24, 48 and 72 h represents the standard of comparison for the objective aid MFE (Fig. 5.18): small cyclones (205, 428 and 660 km), medium cyclones (177, 425 and 663 km) and large cyclones (174, 386 and 594 km).

1. **Dynamical Model (OTCM)**

For small cyclones, the OTCM short-term skill is about 15% worse than CLIPER, while long-range skill is 5% better than CLIPER. This OTCM short-term skill for small cyclones is the worst of any aid in the three subsamples. The reason may lie in the problem of locating the initial position of small cyclones and the bogus vortex in the OTCM may be inappropriate for a small cyclone. An improvement is seen for medium and large cyclones. The OTCM long-range skill is 10% better than CLIPER for medium cyclones, and 15 and 5% better than CLIPER for large cyclones at 48 and 72 h. The decline in skill at 72 h for large cyclones as compared to

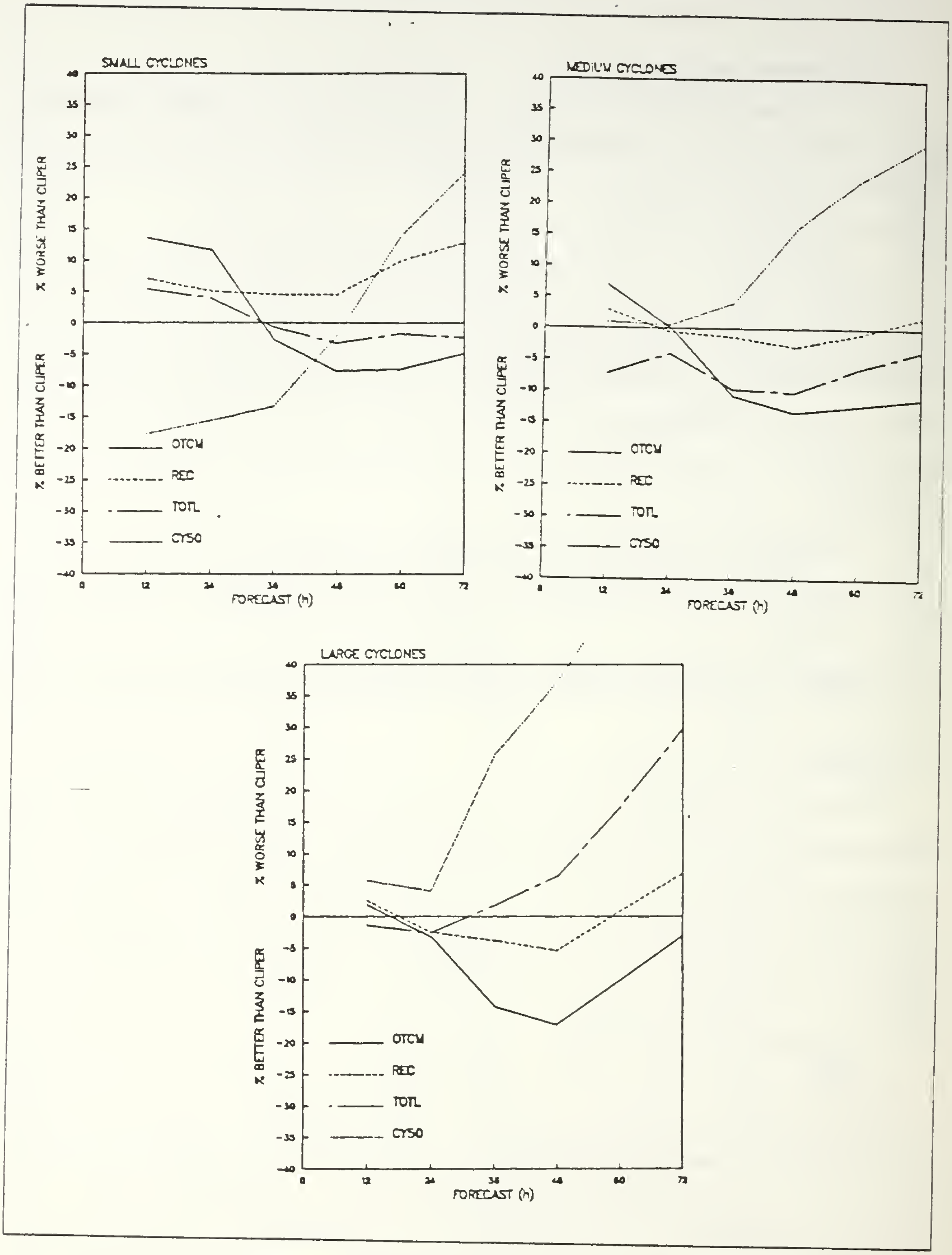

Figure 5.18 As in Fig. 5.1, except for size subsamples.

consistent medium-size cyclone performance may be a result of recurvature errors, because cyclones usually reach their greatest size prior to recurvature (Merrill, 1982).

The OTCM systematic (Fig. 5.19) and CT/AT error (Fig. 5.20) trends are similar to those in previous stratifications. In all cases, the OTCM has CT skill beyond 24 h. As in the NTCM (Chan et al., 1986), the OTCM performance for CT prediction is slightly better for small cyclones. Unlike the OTCM, the NTCM has no apparent skill over CLIPER in forecasting the CT components for large cyclones. Overall, both the NTCM and OTCM show a leftward track bias which may be responsible for long-range forecast errors.

In the AT component (Fig. 5.20), the OTCM has skill only at 24 and 48 h for all sizes of cyclones. Whereas the NTCM has a slow bias in all cases, the OTCM has a fast bias that decreases with increasing cyclone size (Figs. A.26, A.28 and A.30).

The relatively good OTCM performance on large cyclones compared to the the poor NTCM performance may indicate problems with the "nested" grid in the NTCM. Chan et al. (1986) suggests that the large cyclones may lie outside the inner grid of the NTCM.

2. Analogs (REC and TOTL)

The TOTL analog outperforms REC in the small and medium size groups (Fig. 5.18). In the small subsample, REC has no mean error skill, whereas TOTL is only 3% better than CLIPER in the 48 to 72 h period (no skill at 24 h). Both analogs improve in performance in the medium subsample, for which the skill of REC is comparable to CLIPER and TOTL is 5 to 10% better than CLIPER in all forecast intervals. However, REC clearly outperforms TOTL in the large cyclone subsample, although the REC has no skill at 72 h.

The TOTL systematic error trend (Fig. 5.19) is consistent with MFE performance. The TOTL SX errors increase with increasing storm size which results in poor TOTL MFE performance for large cyclones. In contrast to TOTL, REC has large SY errors in all size subsamples.

The analog aids have CT skill only for medium size cyclones (Fig. 5.20). For medium size cyclones, the REC aid outperforms the other aids in 48 - 72 h path prediction skill, and TOTL has the best 24 h CT prediction skill. As in previous stratifications, the northward bias in REC results in the no-skill CT performance for small and large cyclones (Figs. A.25, A.27 and A.29).

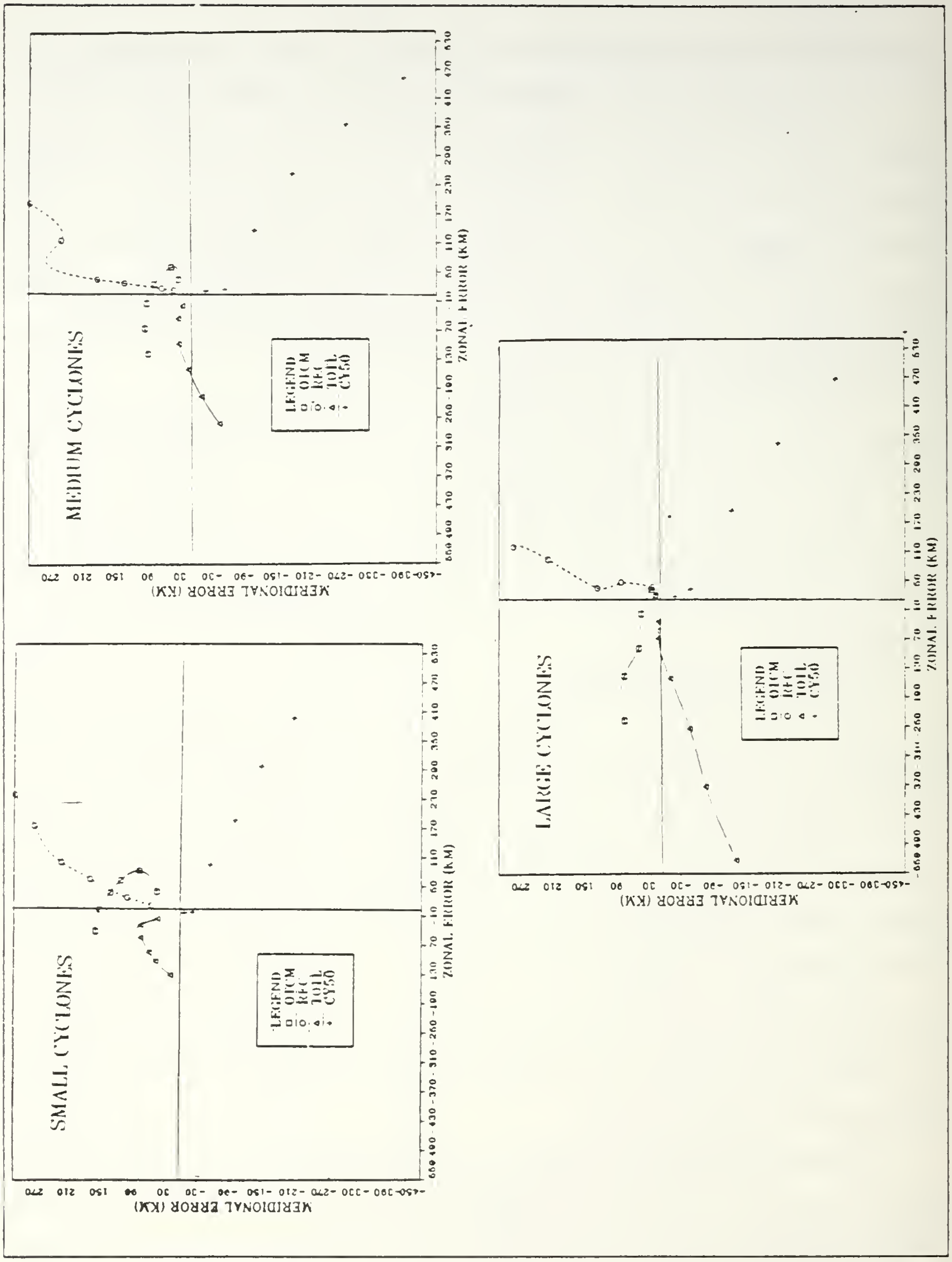

Figure 5.19 As in Fig. 5.2, except for size subsamples.

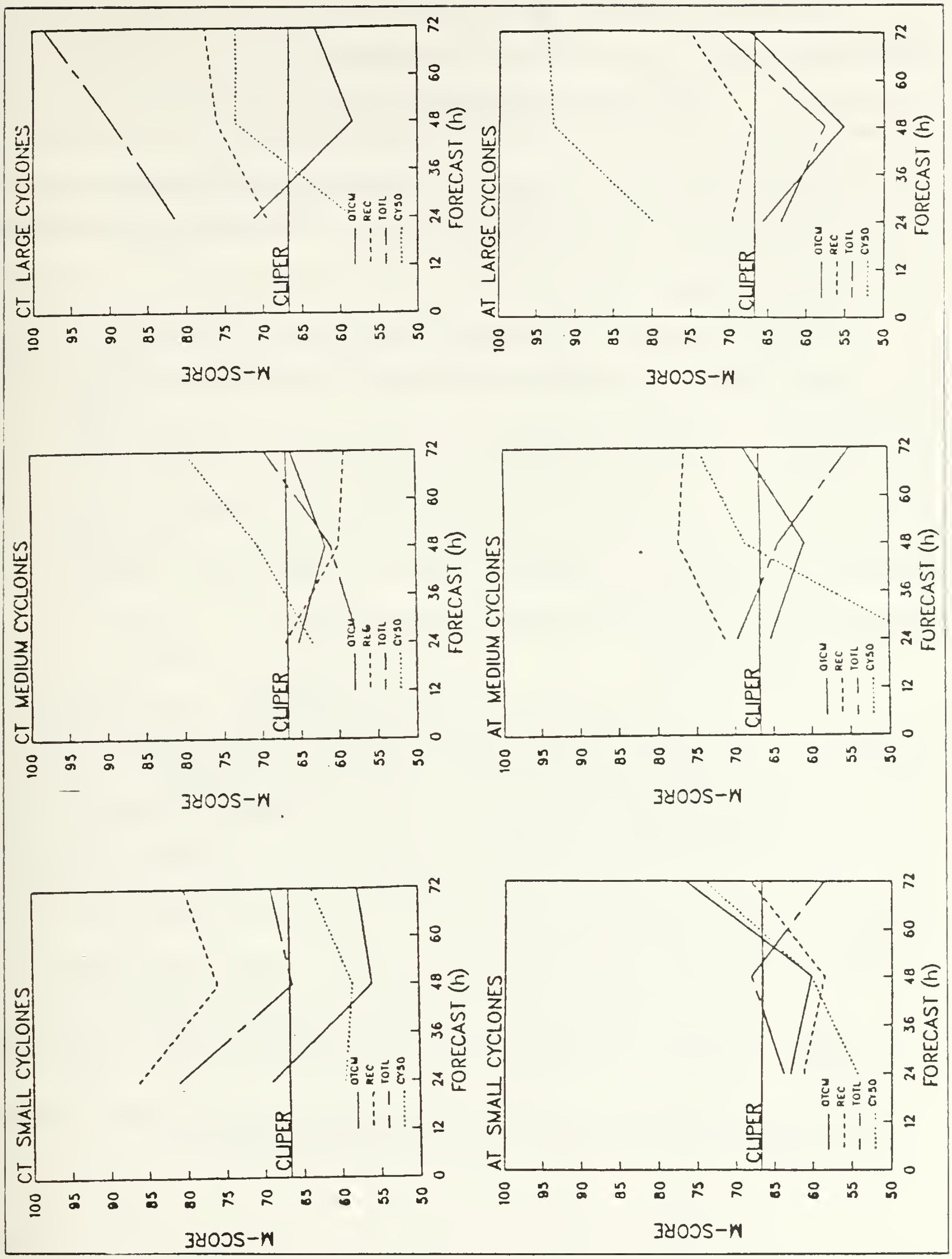

Figure 5.20 As in Fig. 5.3, except for size subsamples.

In the AT components, only the TOTL aid has long-range skill for small and medium size cyclones. The CLIPER aid outperforms all aids in AT skill for large cyclones at 72 h. The REC aid has short-term AT skill only at 24 and 48 h for small cyclones, and no speed prediction skill in the other subsamples. The characteristic fast bias in REC is responsible for the poor AT performance in the medium and large subsamples, whereas an uncharacteristic slow bias in TOTL (Fig. A.30) results in a no-skill AT performance for large cyclones.

3. Steering (CY50)

The CY50 aid shows no mean error skill (Fig. 5.18) in the medium and large cyclone groups. In the small group, CY50 has skill only in the 24 h (19%) to 36 h (10%) period. The CY50 systematic error trends (Fig. 5.19) have a southeastward bias (seen in previous samples) that increases with increasing cyclone size. The CT/AT M-scores show that CY50 has CT prediction skill for only small cyclones and AT prediction skill at 24 h for small and medium cyclones (Fig. 5.20). As in previous stratifications, an excessive slow bias in CY50 is the primary cause of forecast errors, with errors also attributed to the CY50 rightward track bias.

4. **Guidance Summary**

The OTCM has path prediction skill in all subsamples. In speed prediction, the OTCM has no long-range skill because of a fast bias. The analog aids have no CT skill for small and large cyclones as a result of their respective biases. However, the REC outperforms the other aids in path prediction for medium size storms, whereas the TOTL aid has the the best long-range AT skill of any aid for small and medium storms. Finally, the CY50 has no AT or CT skill outside of path prediction skill for small cyclones because of a rightward/slow bias.

1) *Small cyclones* (*R < 135 n mi*). *Path prediction*- CY50 at 24 h and OTCM at 48 and 72 h *Speed prediction*- CY50 at 24 h, REC at 48 h and TOTL at 72 h;

2) *Medium* (*R between 135 and 220 n mi*). *Path prediction*- TOTL at 24 h and REC at 48 and 72 h. *Speed prediction*- CY50 at 24 h, OTCM at 48 h and TOTL at 72 h; and

3) *Large* (*R > 220 n mi*). *Path prediction*- CY50 at 24 h and OTCM at 48 and 72 h. *Speed prediction*- TOTL at 24 h and OTCM at 48 and 72 h.

VI. SYNOPTIC PARAMETER RESULTS

Objective aid performance in terms of synoptic parameters is presented in this chapter. A brief description of the unstratified (total) sample is followed by a discussion of the four synoptic subgroups. Error statistics for the unstratified sample are discussed in the following order: 1) mean forecast errors; 2) systematic errors; and 3) CT/AT errors. The synoptic subgroups are as described in Chapter III:

1) U700-2 > 0 and V250-2 > 0 (low-level easterlies and upper-level trough to the north);
2) U7002 < 0 and V250-2 > 0 (low-level westerlies and upper-level trough to the north);
3) U700-2 > 0 and V250-2 < 0 (low-level easterlies and upper-level ridge to the north); and
4) U700-2 < 0 and V250-2 < 0 (low-level westerlies and upper-level ridge to the north)

A performance summary is given at the end of this chapter. The four synoptic subgroup flow patterns are illustrated in Fig. 6.1.

A. UNSTRATIFIED SYNOPTIC SAMPLE

The objective aid mean error trends (Fig. 6.2) are almost identical to those seen in the storm-related parameters (Fig. 5.1). The CY50 aid is the only exception, as it has a 10% reduction in overall skill. Although both storm-related and synoptic parameter data are taken from warnings issued by JTWC during the 1981 to 1983 seasons, the reduction to 181 (from 356) homogeneous cases has apparently caused the 10% reduction in CY50 skill. The MFE for CLIPER in the synoptic total sample are 183, 418 and 659 km, which are essentially identical to those for the storm-related sample (183, 418 and 639 km). Furthermore, systematic errors trends (Fig. 6.3) are also similar to those in the storm-related sample (Fig. 5.2). The CT/AT M-score variations with time (Fig. 6.4) have only a small reduction in skill and no change in trend compared to the storm-related sample (Fig. 5.3). The CY50 aid is the only exception with no skill in short-term path prediction. Therefore, few significant differences exist between the storm-related and synoptic parameter unstratified samples.

The stratifications (subgroups) based on synoptic parameters will be discussed in the following sections. Error measurements will be examined to see if there are similar features regardless of synoptic-parameter classification.

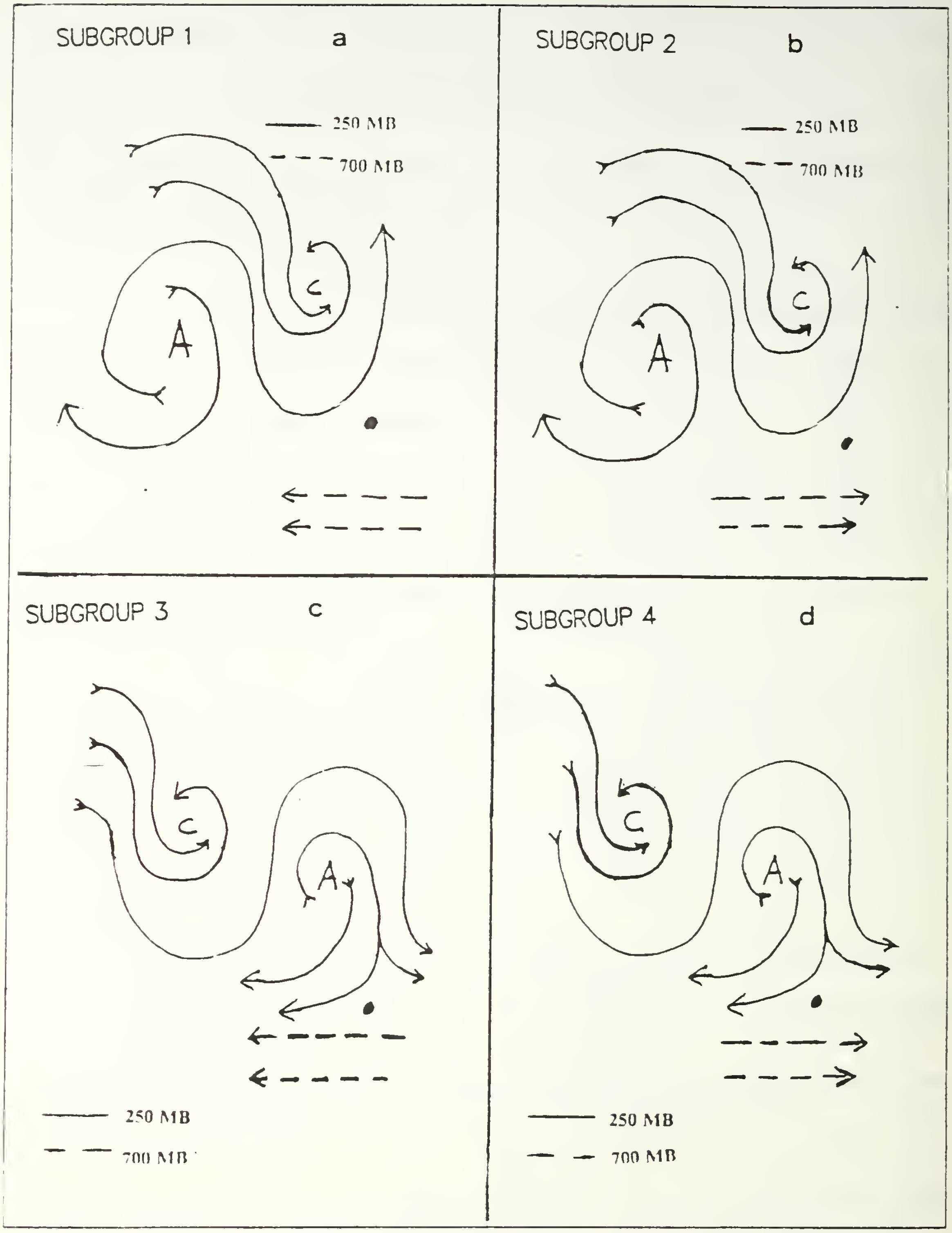

Figure 6.1 Cyclone/anticyclone patterns at 250 mb and corresponding 700 mb zonal flow. Black dot indicates storm center position.

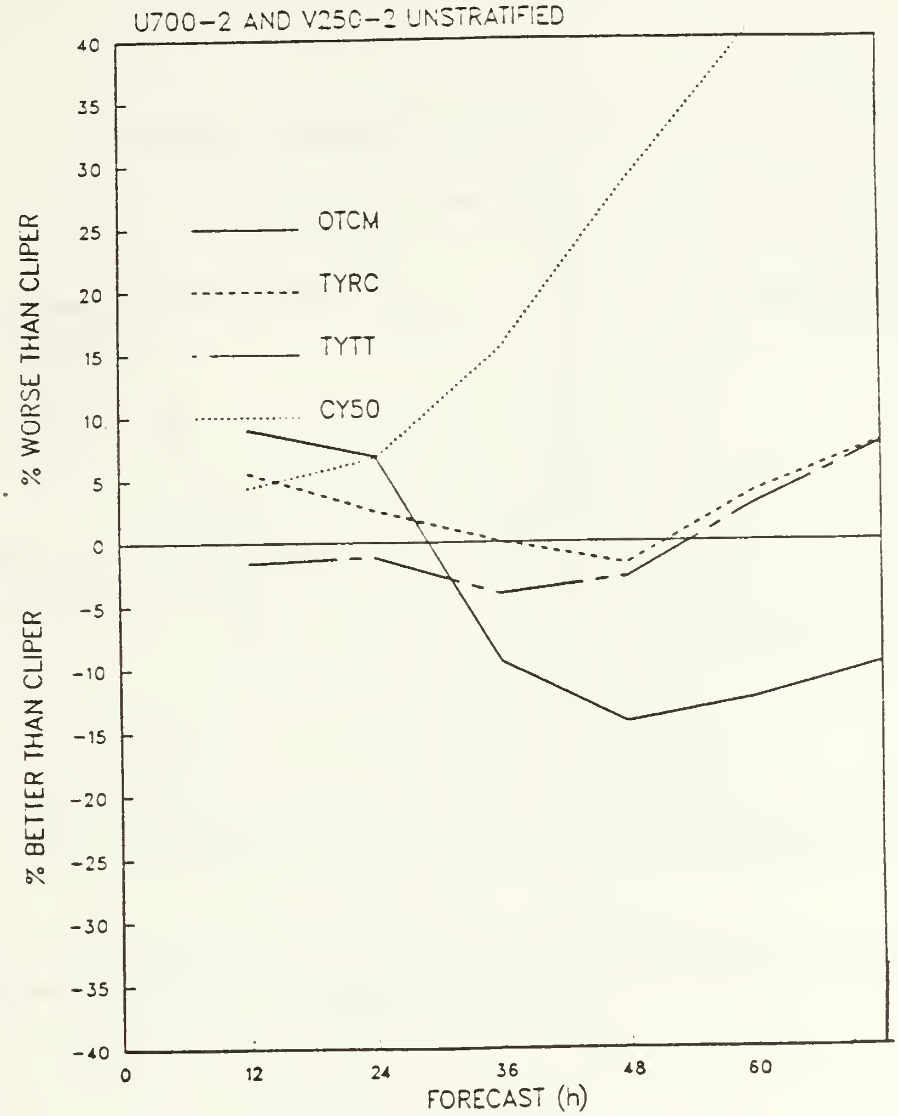

Figure 6.2 Mean forecast errors relative to corresponding CLIPER forecasts for the total synoptic sample of 181 objective aid forecasts.

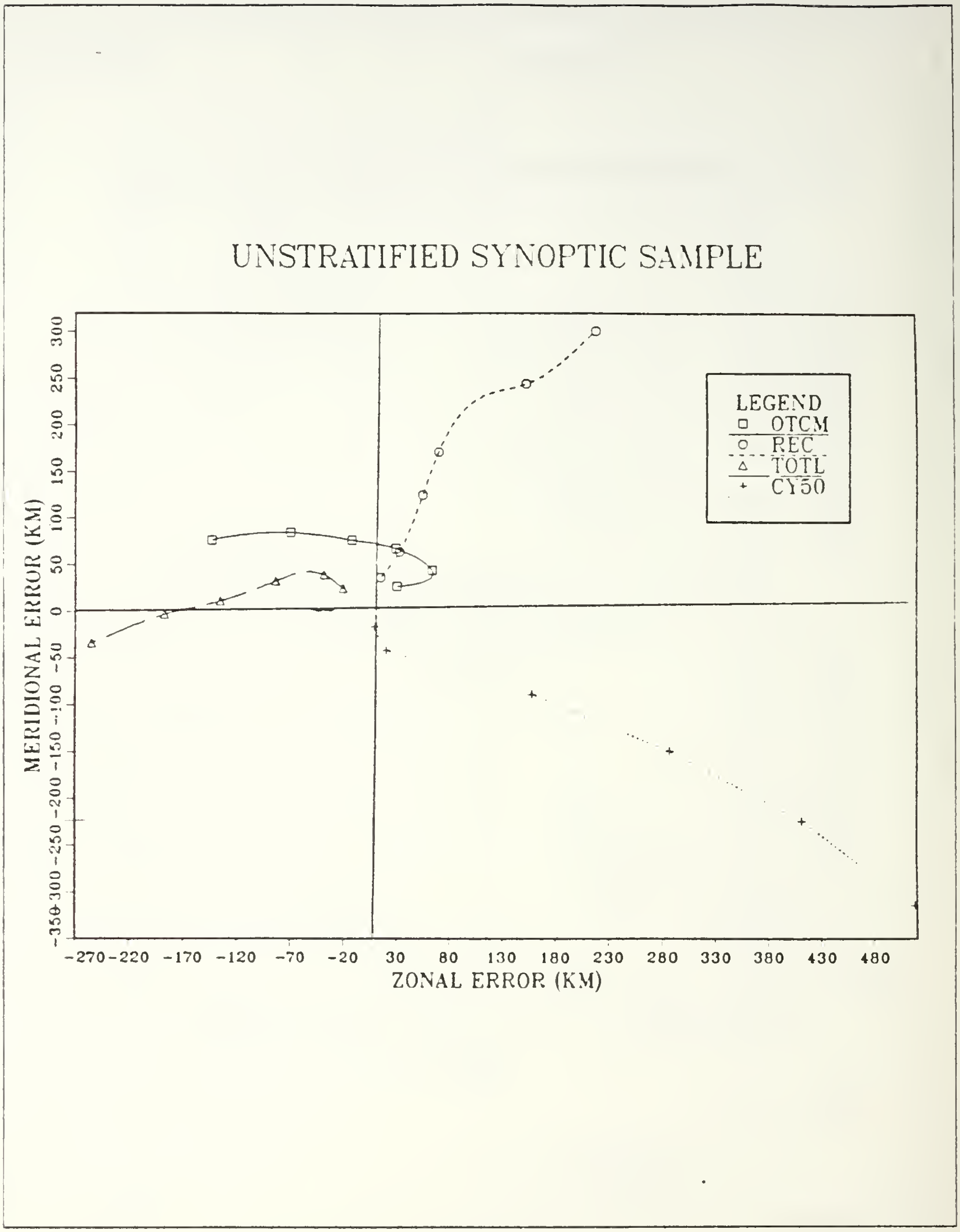

Figure 6.3 Systematic zonal (SX) and meridional (SY) errors for the total synoptic sample of 181 objective aid forecasts. Starting from the origin, the line symbols indicate 12 h intervals (12 to 72 h).

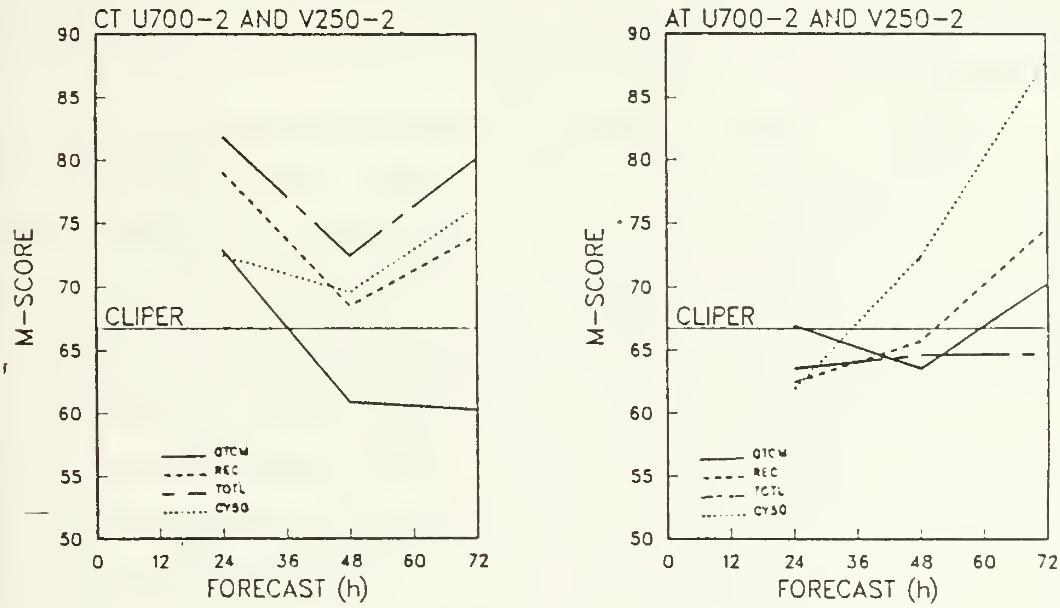

Figure 6.4 Time variations of the CT/AT M-scores for the total synoptic sample of 181 objective aid forecasts.

B. 700 MB EASTERLIES AND 250 MB TROUGH TO THE NORTH

The CLIPER MFE for 24, 48 and 72 h (172, 418 and 673 km) represent the standard of comparision. The synoptic flow pattern for subgroup 1 is provided in Fig. 6.1a. Higher zonal translational speeds are observed in subgroup 1 cyclones compared to subgroups 2 and 4 (Peak et al., 1986).

1. Dynamical Model (OTCM)

In comparison with the performance in the total sample, the OTCM model in this synoptic subgroup (Fig. 6.5) shows a 15 and 10% reduction in short- and long-range skill, respectively, relative to the total sample of OTCM forecasts. Furthermore, this OTCM MFE performance is the worst of the four subgroups with 12 to 24 h period skill 25% worse than CLIPER.

There is no significant difference in the OTCM systematic error trend (Fig. 6.6) compared to the corresponding unstratified sample. However, the CT/AT M-score variation with time (Fig. 6.7) shows that OTCM forecasts in this synoptic subgroup have no significant skill in path prediction. The 2-class CT errors (Fig. 6.8) are higher in this subgroup compared to the total sample. The OTCM does not perform as well on left-turning storms at 24 h, and right-turning and straight-moving storms at 48 and 72 h. In this subgroup, the low-level easterlies tend to advect the cyclone toward the upper-level ridge located to the west (Fig. 6.1a) which inhibits northward meridional motion (Peak et al., 1986). Thus, the initial rightward track bias may result in a higher percentage of left tercile 2-class errors at 24 h. As the storm tracks toward the ridge, the pre-processing technique may overcompensate for the initial track bias and result in a larger leftward track bias than in the total sample.

In speed prediction, the OTCM has a very large slow bias at 24 h that changes to a small fast bias at 48 and 72 h (Fig. 6.9). It is the slow bias that appears to cause the poor short-term AT skill and largest short-term MFE (Fig. 6.5). The AT skill of the OTCM improves as the characteristic fast bias develops at 48 and 72 h.

2. Analogs (REC and TOTL)

The TOTL aid is the only analog method that shows any significant short-range skill (5%) for this synoptic subgroup (Fig. 6.5) and both REC and TOTL have no skill at the 72 h projection (10% worse than CLIPER). As in the OTCM, there are no significant differences in the subgroup 1 and unstratified sample systematic error trends.

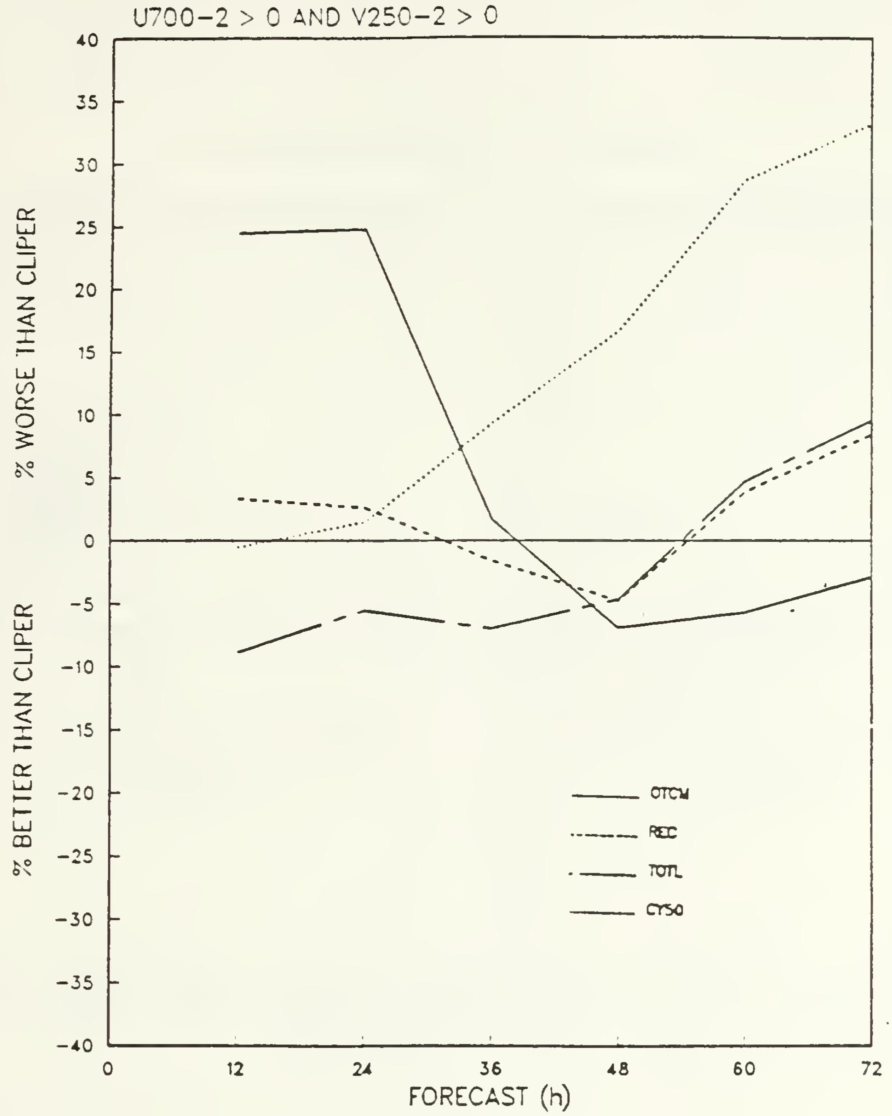

Figure 6.5 As in Fig. 6.2, except for subgroup 1.

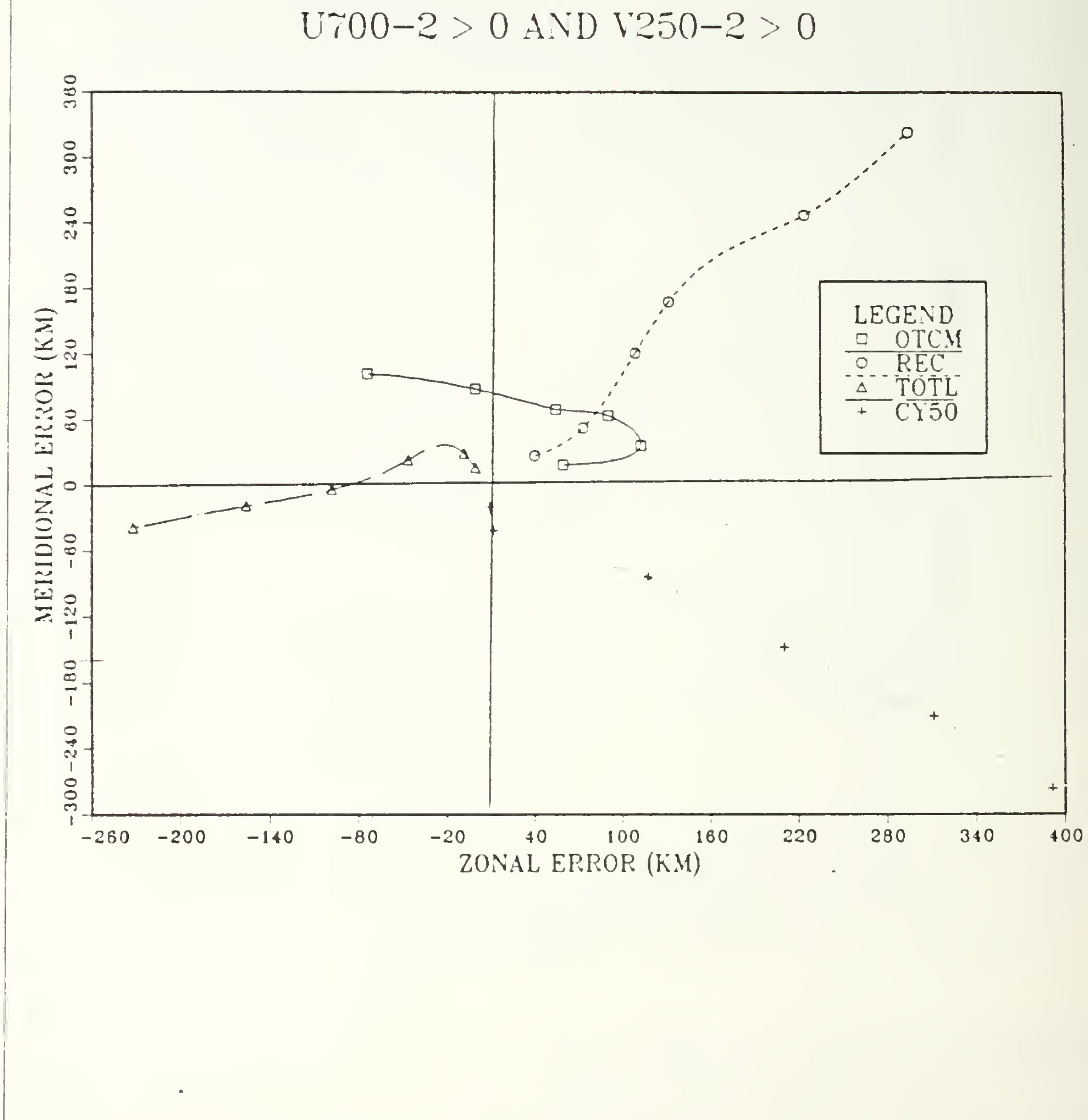

Figure 6.6 As in Fig. 6.3, except for subgroup 1.

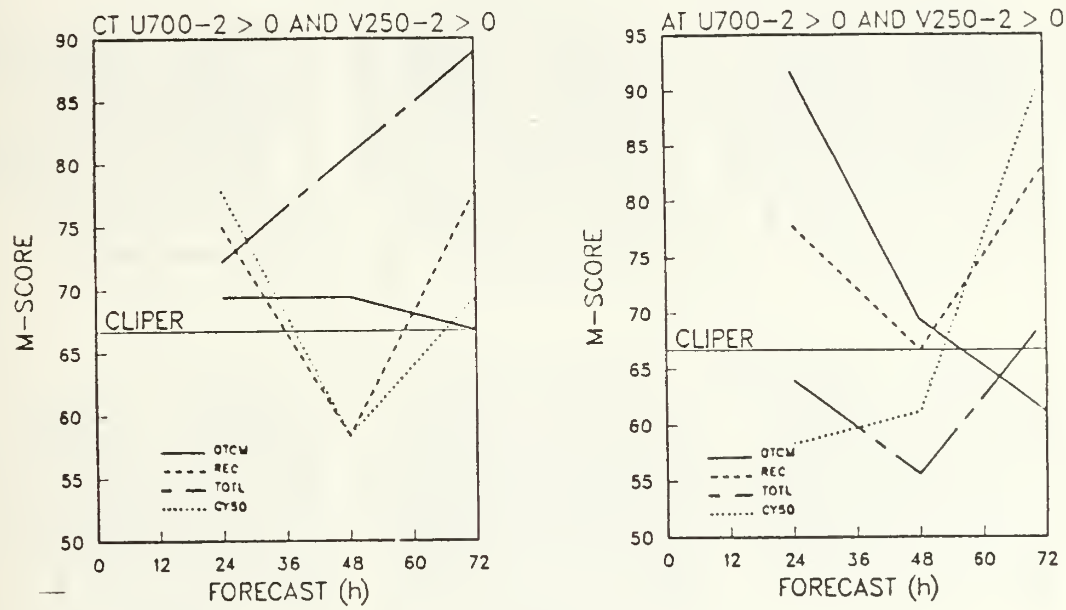

Figure 6.7 As in Fig. 6.4, except for subgroup 1.

24 h OTCM

Best Track	%0	%1	%2
L	41.7	16.7	41.7
C	41.7	58.3	
R	66.7	16.7	16.7
Total	50.0	30.6	19.4

M Score = 69.4

24 h REC

Best Track	%0	%1	%2
L	25.0	41.7	33.3
C	50.0	50.0	
R	41.7	50.0	8.3
Total	38.9	47.2	13.9

M Score = 75.0

24 h TOTL

Best Track	%0	%1	%2
L	50.0	41.7	8.3
C	66.7	33.3	
R	16.7	41.7	41.7
Total	44.4	38.9	16.7

M Score = 72.2

24 h CY50

Best Track	%0	%1	%2
L	83.3	8.3	8.3
C	8.3	91.7	
R	25.0	33.3	41.7
Total	38.9	44.4	16.7

M Score = 77.8

48 h OTCM

Best Track	%0	%1	%2
L	63.6	18.2	18.2
C	33.3	66.7	
R	23.1	69.2	7.7
Total	38.9	52.8	8.3

M Score = 69.4

48 h REC

Best Track	%0	%1	%2
L	36.4	27.3	36.4
C	58.3	41.7	
R	69.2	23.1	7.7
Total	55.6	30.6	13.9

M Score = 58.3

48 h TOTL

Best Track	%0	%1	%2
L	63.6	27.3	9.1
C	50.0	50.0	
R	7.7	46.2	46.2
Total	38.9	41.7	19.4

M Score = 80.6

48 h CY50

Best Track	%0	%1	%2
L	54.5	27.3	18.2
C	50.0	50.0	
R	53.8	30.8	15.4
Total	52.8	36.1	11.1

M Score = 58.3

72 h OTCM

Best Track	%0	%1	%2
L	66.7	25.0	8.3
C	45.5	54.5	
R	15.4	69.2	15.4
Total	41.7	50.0	8.3

M Score = 66.7

72 h REC

Best Track	%0	%1	%2
L	25.0	25.0	50.0
C	27.3	72.7	
R	69.2	23.1	7.7
Total	41.7	38.9	19.4

M Score = 77.8

72 h TOTL

Best Track	%0	%1	%2
L	50.0	33.3	16.7
C	54.5	45.5	
R	0.0	53.8	46.2
Total	33.3	44.4	22.2

M Score = 88.9

72 h CY50

Best Track	%0	%1	%2
L	50.0	25.0	25.0
C	18.2	81.8	
R	61.5	23.1	15.4
Total	44.4	41.7	13.9

M Score = 69.4

Figure 6.8 CT percentage of 0-, 1- and 2-class errors of subgroup 1 for each of the terciles of the best track distribution relative to CLIPER (L-left, C-center, R-right).

24 h — OTCM

Best Track	%0	%1	%2
S	45.5	54.5	0.0
C	15.4	84.6	
F	16.7	33.3	50.0
Total	25.0	58.3	16.7

M Score = 91.7

48 h — OTCM

Best Track	%0	%1	%2
S	16.7	83.3	0.0
C	66.7	33.3	
F	33.3	41.7	25.0
Total	38.9	52.8	8.3

M Score = 69.4

72 h — OTCM

Best Track	%0	%1	%2
S	16.7	83.3	0.0
C	54.5	45.5	
F	53.8	38.5	7.7
Total	41.7	55.6	2.8

M Score = 61.1

24 h — REC

Best Track	%0	%1	%2
S	36.4	63.6	0.0
C	46.2	53.8	
F	8.3	66.7	25.0
Total	30.6	61.1	8.3

M Score = 77.8

48 h — REC

Best Track	%0	%1	%2
S	16.7	83.3	0.0
C	83.3	16.7	
F	8.3	83.3	8.3
Total	36.1	61.1	2.8

M Score = 66.7

72 h — REC

Best Track	%0	%1	%2
S	0.0	83.3	16.7
C	72.7	27.3	
F	15.4	69.2	15.4
Total	27.8	61.1	11.1

M Score = 83.3

24 h — TOTL

Best Track	%0	%1	%2
S	9.1	81.8	9.1
C	69.2	30.8	
F	41.7	50.0	8.3
Total	41.7	52.8	5.6

M Score = 63.9

48 h — TOTL

Best Track	%0	%1	%2
S	33.3	66.7	0.0
C	83.3	16.7	
F	16.7	83.3	0.0
Total	44.4	55.6	0.0

M Score = 55.6

72 h — TOTL

Best Track	%0	%1	%2
S	50.0	50.0	0.0
C	63.6	36.4	
F	7.7	69.2	23.1
Total	38.9	52.8	8.3

M Score = 69.4

24 h — CY50

Best Track	%0	%1	%2
S	63.6	36.4	0.0
C	38.5	61.5	
F	50.0	25.0	25.0
Total	50.0	41.7	8.3

M Score = 58.3

48 h — CY50

Best Track	%0	%1	%2
S	83.3	16.7	0.0
C	50.0	50.0	
F	25.0	33.3	41.7
Total	52.8	33.3	13.9

M Score = 61.1

72 h — CY50

Best Track	%0	%1	%2
S	83.3	8.3	8.3
C	18.2	81.8	
F	7.7	23.1	69.2
Total	36.1	36.1	27.8

M Score = 91.7

Figure 6.9 As in Fig. 6.8, except for along-track (AT) components (S-slow, C-center, F-fast relative to CLIPER).

The CT/AT profiles for TOTL show no skill in CT prediction (Fig. 6.7). As in the total sample, a leftward bias (Fig. 6.8) is responsible for the no-skill in path prediction. The REC still has a rightward track bias that results in no CT skill at 24 and 72 h. However, REC performs well in path prediction at 48 h, especially on straight-moving storms.

As in the total sample, the REC has no speed prediction skill (Fig. 6.7). Unlike the total sample, REC performs poorly on both fast and slow-moving storms in this synoptic subgroup (Fig. 6.9) as a result of a high percentage of AT 1-class errors. The TOTL aid is once again the best aid for speed prediction. The characteristic fast bias in TOTL does well on the subgroup 1 fast-moving and moderate speed storms. Unlike the OTCM, the TOTL is unable to predict the long-range fast motion of these storms, which results in an uncharacteristic poor performance on fast-moving storms at 72 h (Fig. 6.9).

3. **Steering (CY50)**

The CY50 aid shows no significant skill in this subgroup (Fig. 6.5). The short-range skill is comparable to CLIPER, but shows a sharp decline in the 72 h projection (35 % worse than CLIPER). Furthermore, there is no significant difference in systematic error trend (Fig. 6.6) compared to the unstratified sample.

However, the CY50 is one of only two aids that show CT skill at 48 h. As in the unstratified sample, an initial leftward track bias is replaced by a long-range rightward track bias (Fig. 6.8). However, the subgroup 1 biases are of a greater magnitude than in the unstratified sample.

C. 700 MB WESTERLIES AND 250 MB TROUGH TO THE NORTH

The CLIPER MFE for 24, 48 and 72 h (192, 449 and 728 km) represent the standard of comparison. The synoptic flow pattern for subgroup 2 is provided in Fig. 6.1b. In subgroup 2, the low-level westerly flow tends to retard storm movement toward the upper-level ridge to the west (Peak et al., 1986).

1. **Dynamical Model (OTCM)**

In comparison to subgroup 1, the OTCM shows a reduction in short-range mean errors (Fig. 6.10) and a 5% improvement in long-range skill (15% better than CLIPER). Smaller systematic errors are responsible for this improved performance (Fig. 6.11). Moreover, this is the only subgroup in which the OTCM shows a northward bias rather than the usual westward bias at longer ranges.

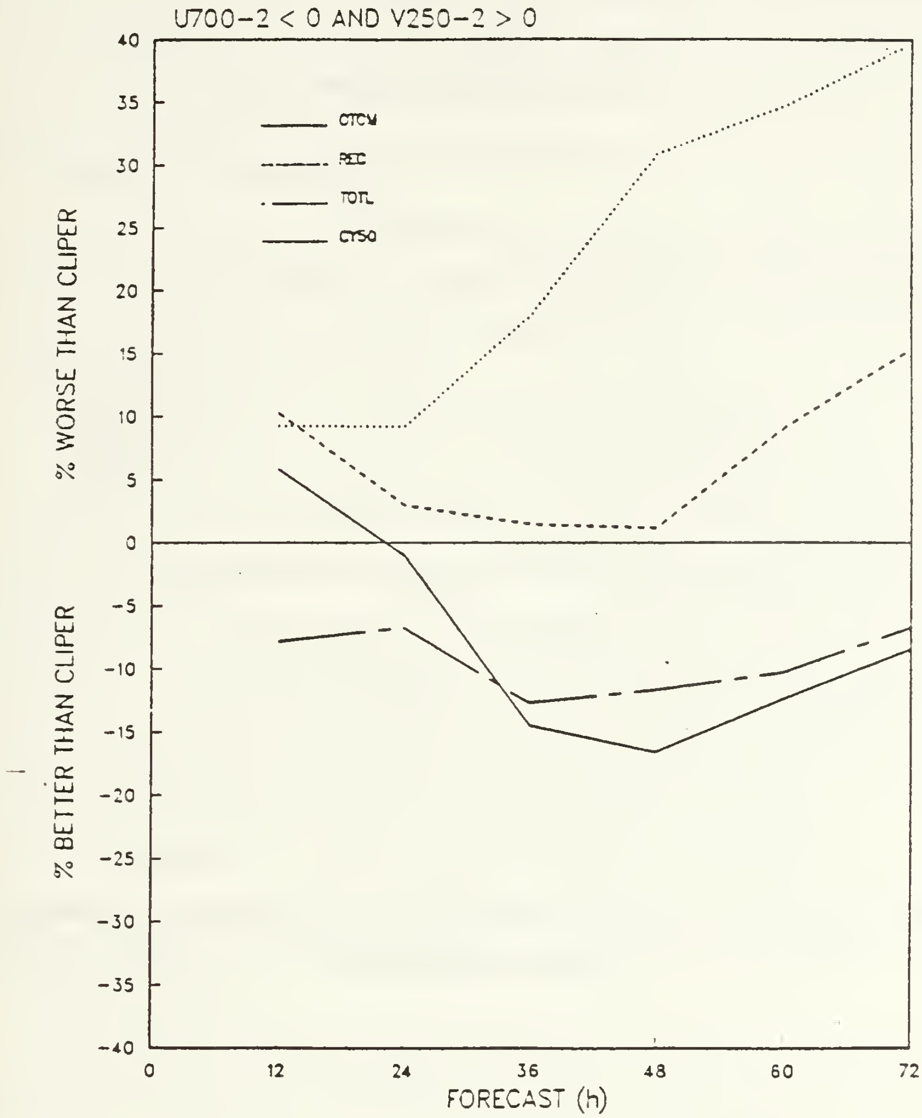

Figure 6.10 As in Fig. 6.2, except for subgroup 2.

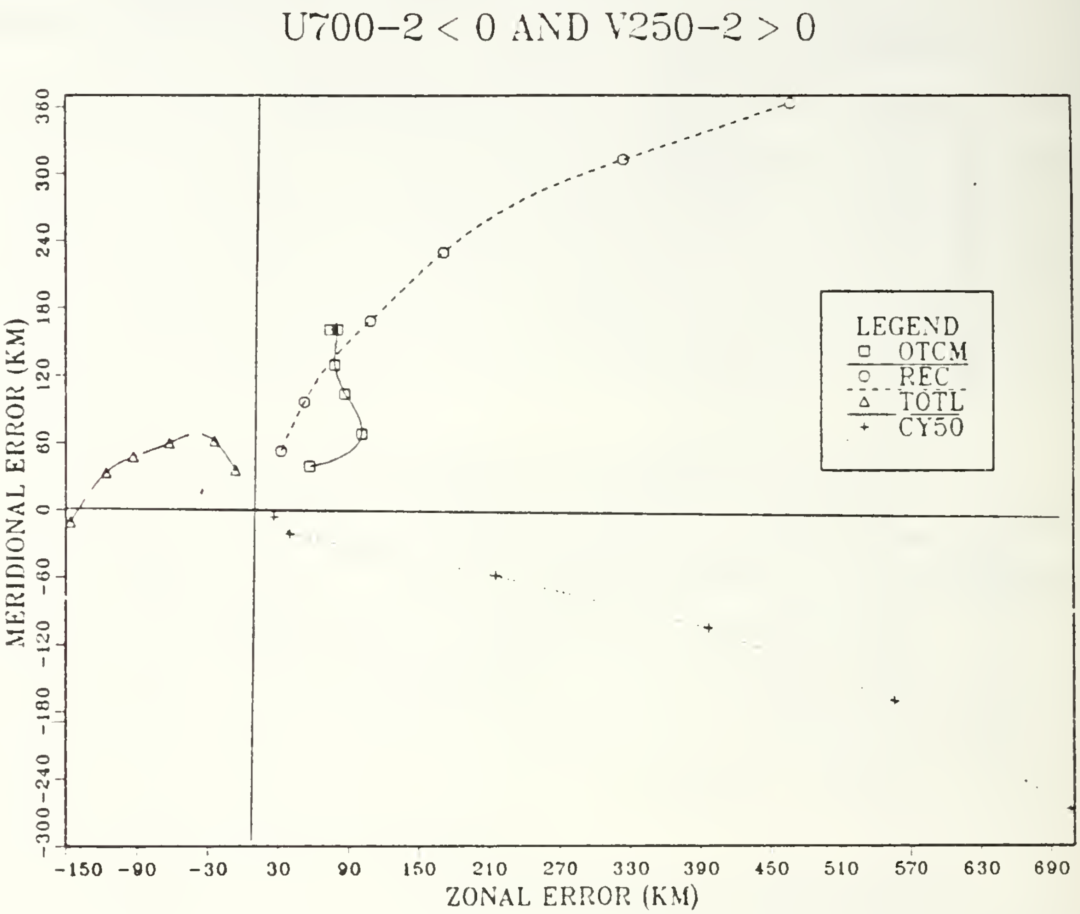

Figure 6.11 As in Fig. 6.3, except for subgroup 2.

The CT/AT M-score variations with time (Fig. 6.12) show that the OTCM has long-range skill in both path and speed prediction. In the CT component, the 2-class CT errors in the left tercile (right bias) decrease to zero by 72 h (Fig. 6.13), with an increase in 24 and 72 h CT 1-class errors compared to the total sample. Because the northward meridional motion is only slightly greater than in subgroup 1, an overall reduction in storm speed is observed. This reduction in storm speed may cause the reduction in CT 2-class errors.

2. Analogs (REC and TOTL)

The REC aid has no MFE skill in this subgroup, whereas TOTL is 7 to 10% better than CLIPER throughout the forecast period (Fig. 6.10). The systematic error trend (Fig. 6.11) indicates the smallest westward TOTL bias of any subgroup, while the REC has the largest northeastward bias.

Unlike in subgroup 1, the REC has no path prediction skill, whereas TOTL now has CT skill at 48 h only (Fig. 6.12). The larger rightward REC bias may be a result of the REC analog sample including a larger meridional translation than in subgroup 1. This characteristic and the slower cyclone speeds may indicate a recurving situation in the REC analog scheme. However, the upper-level ridge and slow cyclone speeds may retard severe right-turning motion and result in a high percentage of 2-class CT errors for REC in the left tercile at 24 and 48 h (Fig. 6.13). The TOTL does well on the left-turning storms and poorly on right-turning storms at 48 and 72 h. The return to a leftward track bias results in CT skill at 48 h.

In AT prediction, the REC aid has no skill beyond 24 h as a result of a growing fast bias (Fig. 6.14). The TOTL aid has a fast bias and AT skill at 72 h. These results are consistent with the slower cyclone speeds found in this subgroup.

3. Steering (CY50)

The CY50 aid has no MFE skill in this subgroup (Fig. 6.10). Short and long-range performance is 10 and 40% worse than CLIPER, respectively. Systematic (Fig. 6.11) and CT/AT class errors (Figs. 6.13 and 6.14) suggest that the CY50 southeastward(rightward)/slow bias is responsible for the absence of skill in this subgroup. In this subgroup, the CY50 has no CT skill and no AT skill beyond 24 h (Fig. 6.12).

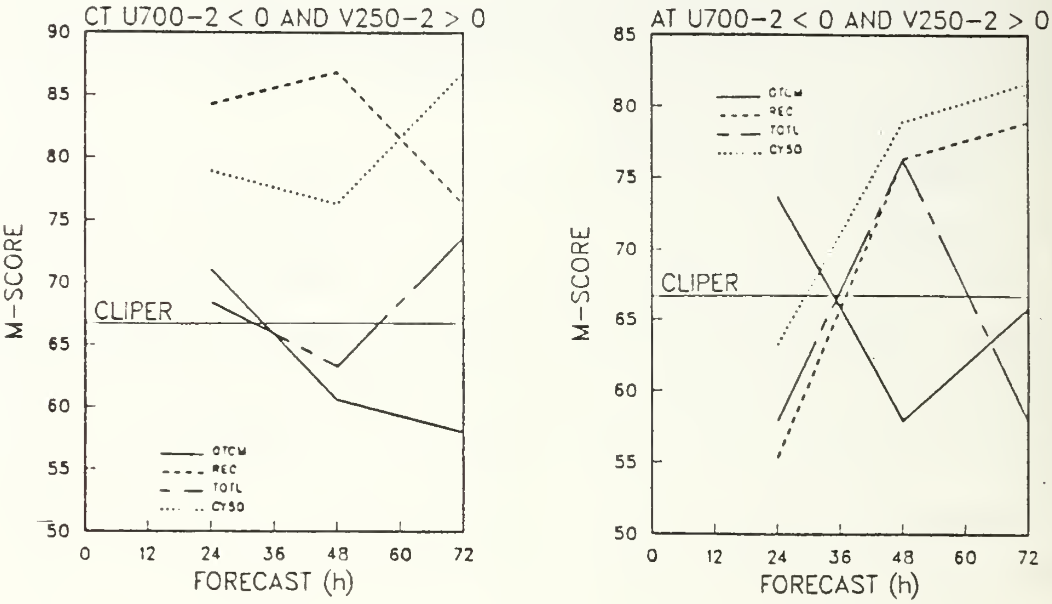

Figure 6.12 As in Fig. 6.4, except for subgroup 2.

24 h OTCM

Best Track	%0	%1	%2
L	45.5	27.3	27.3
C	14.3	85.7	
R	61.5	30.8	7.7
Total	39.5	50.0	10.5

M Score = 71.1

24 h REC

Best Track	%0	%1	%2
L	0.0	45.5	54.5
C	35.7	64.3	
R	53.8	46.2	0.0
Total	31.6	52.6	15.8

M Score = 84.2

24 h TOTL

Best Track	%0	%1	%2
L	18.2	63.6	18.2
C	50.0	50.0	
R	53.8	30.8	15.4
Total	42.1	47.4	10.5

M Score = 68.4

24 h CY50

Best Track	%0	%1	%2
L	27.3	45.5	27.3
C	71.4	28.6	
R	23.1	38.5	38.5
Total	42.1	36.8	21.1

M Score = 78.9

48 h OTCM

Best Track	%0	%1	%2
L	50.0	25.0	25.0
C	35.7	64.3	
R	58.3	41.7	0.0
Total	47.4	44.7	7.9

M Score = 60.5

48 h REC

Best Track	%0	%1	%2
L	8.3	33.3	58.3
C	21.4	78.6	
R	66.7	33.3	0.0
Total	31.6	50.0	18.4

M Score = 86.8

48 h TOTL

Best Track	%0	%1	%2
L	66.7	33.3	0.0
C	50.0	50.0	
R	16.7	58.3	25.0
Total	44.7	47.4	7.9

M Score = 63.2

48 h CY50

Best Track	%0	%1	%2
L	25.0	33.3	41.7
C	50.0	50.0	
R	33.3	66.7	0.0
Total	36.8	50.0	13.2

M Score = 76.3

72 h OTCM

Best Track	%0	%1	%2
L	45.5	54.5	0.0
C	46.7	53.3	
R	33.3	66.7	0.0
Total	42.1	57.9	0.0

M Score = 57.9

72 h REC

Best Track	%0	%1	%2
L	18.2	54.5	27.3
C	20.0	80.0	
R	58.3	41.7	0.0
Total	31.6	60.5	7.9

M Score = 76.3

72 h TOTL

Best Track	%0	%1	%2
L	63.6	36.4	0.0
C	53.3	46.7	
R	0.0	58.3	41.7
Total	39.5	47.4	13.2

M Score = 73.7

72 h CY50

Best Track	%0	%1	%2
L	0.0	45.5	54.5
C	46.7	53.3	
R	41.7	50.0	8.3
Total	31.6	50.0	18.4

M Score = 86.8

Figure 6.13 As in Fig. 6.8, except for subgroup 2.

24 h — OTCM

Best Track	%0	%1	%2
S	27.3	63.6	9.1
C	53.3	46.7	
F	25.0	50.0	25.0
Total	36.8	52.8	10.5

M Score = 73.7

24 h — REC

Best Track	%0	%1	%2
S	18.2	72.7	9.1
C	93.3	6.7	
F	25.0	66.7	8.3
Total	50.0	44.7	5.3

M Score = 55.3

24 h — TOTL

Best Track	%0	%1	%2
S	9.1	72.7	18.2
C	73.3	26.7	
F	50.0	50.0	0.0
Total	47.4	47.4	5.3

M Score = 57.9

24 h — CY50

Best Track	%0	%1	%2
S	27.3	72.7	0.0
C	60.0	40.0	
F	33.3	50.0	16.7
Total	42.1	52.6	5.3

M Score = 63.2

48 h — OTCM

Best Track	%0	%1	%2
S	50.0	25.0	25.0
C	53.8	46.2	
F	61.5	23.1	15.4
Total	55.3	31.6	13.2

M Score = 57.9

48 h — REC

Best Track	%0	%1	%2
S	8.3	41.7	50.0
C	61.5	38.5	
F	53.8	38.5	7.7
Total	42.1	39.5	18.4

M Score = 76.3

48 h — TOTL

Best Track	%0	%1	%2
S	16.7	50.0	33.3
C	7.7	92.3	
F	76.9	23.1	0.0
Total	34.2	55.3	10.5

M Score = 76.3

48 h — CY50

Best Track	%0	%1	%2
S	75.0	16.7	8.3
C	53.8	46.2	
F	7.7	30.8	61.5
Total	44.7	31.6	23.7

M Score = 78.9

72 h — OTCM

Best Track	%0	%1	%2
S	41.7	33.3	25.0
C	38.5	61.5	
F	69.2	7.7	23.1
Total	50.0	34.2	15.8

M Score = 65.8

72 h — REC

Best Track	%0	%1	%2
S	8.3	33.3	58.3
C	46.2	53.8	
F	61.5	38.5	0.0
Total	39.5	42.1	18.4

M Score = 78.9

72 h — TOTL

Best Track	%0	%1	%2
S	41.7	33.3	25.0
C	53.8	46.2	
F	53.8	46.2	0.0
Total	50.0	42.1	7.9

M Score = 57.9

72 h — CY50

Best Track	%0	%1	%2
S	66.7	25.0	8.3
C	38.5	61.5	
F	7.7	46.2	46.2
Total	36.8	44.7	18.4

M Score = 81.6

Figure 6.14 As in Fig. 6.9, except for subgroup 2.

D. 700 MB EASTERLIES AND 250 MB RIDGE TO THE NORTH

The CLIPER MFE for 24, 48 and 72 h (178, 413 and 675 km) represent the standard of comparison. The synoptic flow pattern for subgroup 3 is given in Fig. 6.1c. In subgroup 3, the low-level easterly flow tends to advect the cyclones toward the upper-level trough to the west, which results in greater northward meridional motion than in subgroups 1 and 2 (Peak et al., 1986).

1. Dynamical Model (OTCM)

In comparison to subgroups 1 and 2, the OTCM shows improvement in long-range skill for this synoptic subgroup. The OTCM performance is 18 and 11% better than CLIPER at 48 and 72 h, respectively (Fig. 6.15). However, this subgroup also has the largest OTCM zonal errors (-360 km) and smallest meridional errors (10 km) at 72 h of any subgroup (Fig. 6.16).

The CT/AT M-score variation with time (Fig. 6.17) shows that the OTCM has skill in speed and path prediction at all forecast periods. Although the AT class errors show the characteristic slow at 24 h and fast at 72 h biases for the OTCM (Fig. 6.19), the CT class errors show a left-of-track bias at all forecast projections (Fig. 6.18). Usually, the OTCM has a rightward track bias at 24 h, but performs well with the left-turning storms in this subgroup.

As in subgroup 1, cyclones have greater zonal motion than in subgroups 2 and 4. However, the additional northward motion in this subgroup may account for the leftward track bias and slight reduction in slow bias at 24 h (Figs. 6.18 and 6.19).

2. Analogs (REC and TOTL)

In this subgroup, the REC has its best performance, while TOTL has its worst (Fig. 6.15). In fact, the TOTL aid has no skill in this subgroup, while the REC is 5% better than CLIPER at 48 h. In the systematic error trend (Fig. 6.16), there is no significant difference in TOTL compared to the unstratified sample. However, the REC has a significant reduction in SX errors.

Consistent with the systematic error trend, the REC 2-class CT errors indicate only small track biases (Fig. 6.18), whereas the TOTL 2-class CT errors have a large leftward track bias. Thus, the TOTL aid has no CT skill and REC has path prediction skill at 48 h only (Fig. 6.17). A high percentage of 1-class CT errors in the left tercile of REC (right bias) results in no CT skill at 72 h. These performances are consistent with the greater northward storm motion in subgroup 3.

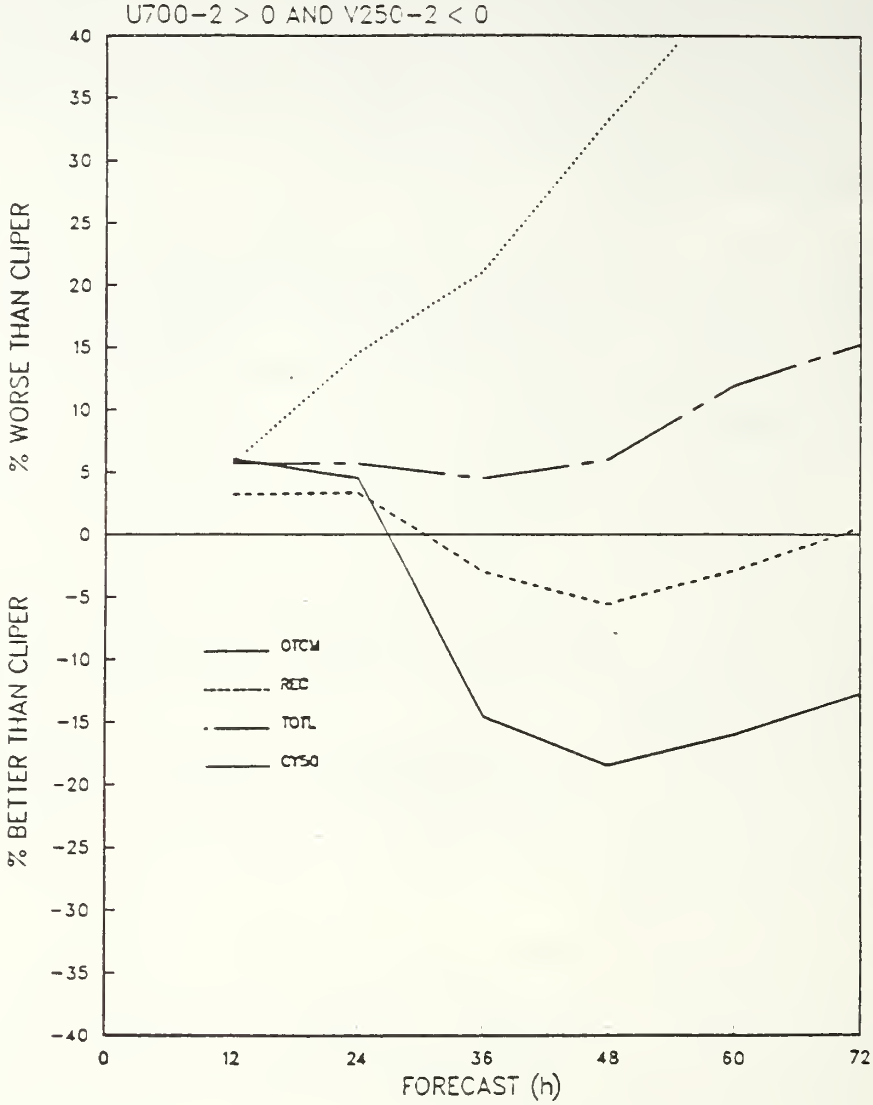

Figure 6.15 As in Fig. 6.2, except for subgroup 3.

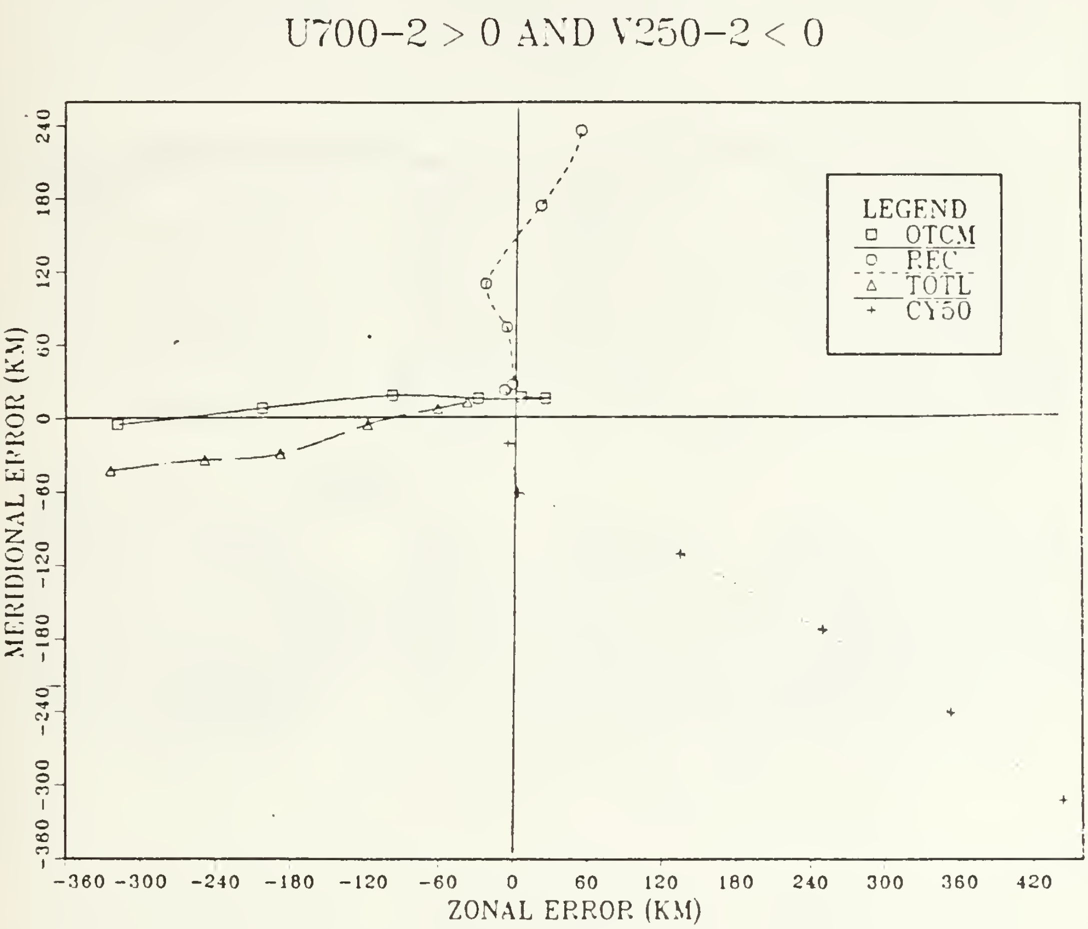

Figure 6.16 As in Fig. 6.3, except for subgroup 3.

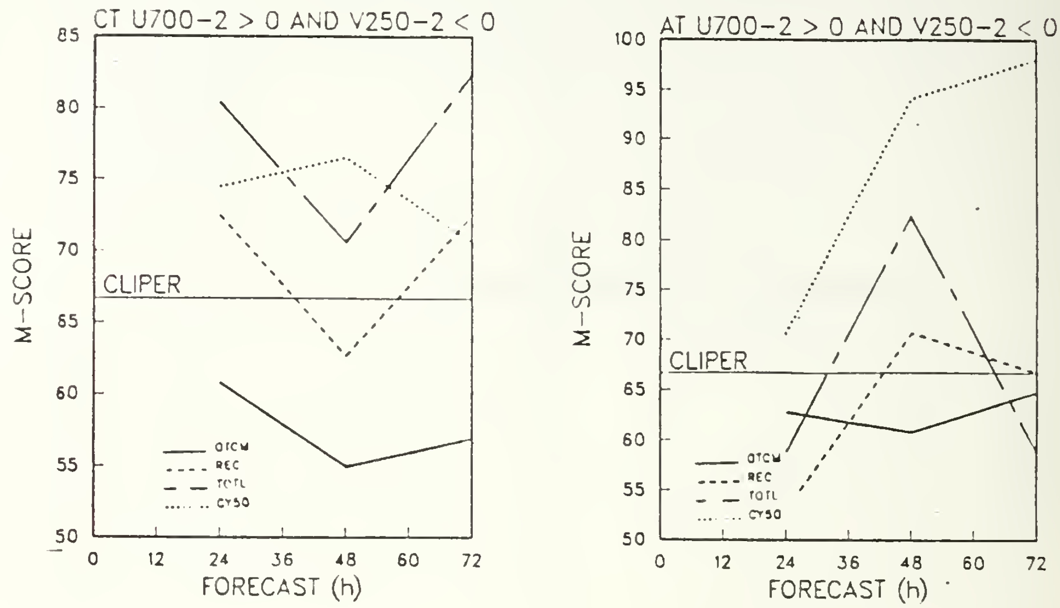

Figure 6.17 As in Fig. 6.4, except for subgroup 3.

24 h — OTCM

Best Track	%0	%1	%2
L	62.5	37.5	0.0
C	16.7	83.3	
R	64.7	11.8	23.5
Total	47.1	45.1	7.8

M Score = 60.8

24 h — REC

Best Track	%0	%1	%2
L	31.3	56.3	12.5
C	44.4	55.6	
R	35.3	47.1	17.6
Total	37.3	52.9	9.8

M Score = 72.5

24 h — TOTL

Best Track	%0	%1	%2
L	75.0	18.8	6.3
C	22.2	77.8	
R	11.8	47.1	41.2
Total	35.3	49.0	15.7

M Score = 80.4

24 h — CY50

Best Track	%0	%1	%2
L	50.0	43.0	6.3
C	22.2	77.8	
R	29.4	52.9	17.6
Total	33.3	58.8	7.3

M Score = 74.5

48 h — OTCM

Best Track	%0	%1	%2
L	70.6	29.4	0.0
C	41.2	58.8	
R	41.2	41.2	17.6
Total	51.0	43.1	5.9

M Score = 54.9

48 h — RECT

Best Track	%0	%1	%2
L	41.2	52.9	5.9
C	47.1	52.9	
R	35.3	58.8	5.9
Total	41.2	54.9	3.9

M Score = 62.7

48 h — TOTL

Best Track	%0	%1	%2
L	76.5	17.6	5.9
C	52.9	47.1	
R	5.9	52.9	41.2
Total	45.1	39.2	15.7

M Score = 70.6

48 h — CY50

Best Track	%0	%1	%2
L	41.2	29.4	29.4
C	35.3	64.7	
R	35.3	52.9	11.8
Total	37.3	49.0	13.7

M Score = 76.5

72 h — OTCM

Best Track	%0	%1	%2
L	75.0	25.0	0.0
C	50.0	50.0	
R	29.4	47.1	23.5
Total	51.0	41.2	7.8

M Score = 56.9

72 h — RECT

Best Track	%0	%1	%2
L	25.0	62.5	12.5
C	27.8	72.2	
R	47.1	47.1	5.9
Total	33.3	60.8	5.9

M Score = 72.5

72 h — TOTL

Best Track	%0	%1	%2
L	75.0	12.5	12.5
C	44.4	55.6	
R	0.0	47.1	52.9
Total	39.2	39.2	21.6

M Score = 82.4

72 h — CY50

Best Track	%0	%1	%2
L	37.5	37.5	25.0
C	44.4	55.6	
R	41.2	47.1	11.8
Total	41.2	47.1	11.8

M Score = 70.6

Figure 6.18 As in Fig. 6.8, except for subgroup 3.

24 h OTCM

Best Track	%0	%1	%2
S	64.7	23.5	11.8
C	52.9	47.1	
F	47.1	11.8	41.2
Total	54.9	27.5	17.6

M Score = 62.7

24 h REC

Best Track	%0	%1	%2
S	58.8	41.2	0.0
C	52.9	47.1	
F	41.2	47.1	11.8
Total	51.0	45.1	3.9

M Score = 52.9

24 h TOTL

Best Track	%0	%1	%2
S	17.6	70.6	11.8
C	52.9	47.1	
F	70.6	23.5	5.9
Total	47.1	47.1	5.9

M Score = 58.8

24 h CY50

Best Track	%0	%1	%2
S	41.2	23.5	35.3
C	35.3	64.7	
F	58.8	29.4	11.8
Total	45.1	39.2	15.7

M Score = 70.6

48 h OTCM

Best Track	%0	%1	%2
S	52.9	29.4	17.6
C	37.5	62.5	
F	61.1	22.2	16.7
Total	51.0	37.3	11.8

M Score = 60.8

48 h RECT

Best Track	%0	%1	%2
S	17.6	35.3	47.1
C	50.0	50.0	
F	72.2	22.2	5.6
Total	47.1	35.3	17.6

M Score = 70.6

48 h TOTL

Best Track	%0	%1	%2
S	35.3	17.6	47.1
C	25.0	75.0	
F	55.6	27.8	16.7
Total	39.2	39.2	21.6

M Score = 82.4

48 h CY50

Best Track	%0	%1	%2
S	52.9	5.9	41.2
C	12.5	87.5	
F	27.8	38.9	33.3
Total	31.4	43.1	25.5

M Score = 94.1

72 h OTCM

Best Track	%0	%1	%2
S	41.2	29.4	29.4
C	29.4	70.6	
F	64.7	35.3	0.0
Total	45.1	45.1	9.8

M Score = 64.7

72 h RECT

Best Track	%0	%1	%2
S	23.5	52.9	23.5
C	35.3	64.7	
F	70.6	23.5	5.9
Total	43.1	47.1	9.8

M Score = 66.7

72 h TOTL

Best Track	%0	%1	%2
S	35.3	47.1	17.6
C	58.8	41.2	
F	64.7	17.6	17.6
Total	52.9	35.3	11.8

M Score = 58.8

72 h CY50

Best Track	%0	%1	%2
S	52.9	11.8	35.3
C	5.9	94.1	
F	11.8	58.8	29.4
Total	23.5	54.9	21.6

M Score = 98.0

Figure 6.19 As in Fig. 6.9, except for subgroup 3.

In speed prediction, both the REC and TOTL have 24 h skill and no 48 h skill. A high percentage of 2-class AT errors in the slow tercile (fast bias) is the reason for the lack of skill in AT prediction at 48 h (Fig. 6.19). However, these errors decrease after 48 h, which results in AT skill at 72 h.

3. Steering (CY50)

The CY50 aid has no MFE skill in this subgroup (Fig. 6.15). The CT/AT M-score variation with time (Fig. 6.17) shows that CY50 has no skill in path or speed prediction. As in previous subgroups, the growing rightward/slow bias appears responsible for the CY50 poor performance (Figs. 6.18 and 6.19).

E. 700 MB WESTERLIES AND 250 MB RIDGE TO THE NORTH

The CLIPER MFE for 24, 48 and 72 h (184, 400 and 586 km) is the standard of comparison. The synoptic flow pattern for subgroup 4 is given in Fig. 6.1d. In subgroup 4, the low-level westerlies retard westward motion although a higher northward translation occurs than in subgroups 1 and 2 (Peak et al., 1986).

1. Dynamical Model (OTCM)

The OTCM model has its best long-range mean error performance in this subgroup (Fig. 6.20). In contrast to the other groups, no decline is observed between 48 and 72 h forecasts (16% better than CLIPER). In the systematic error trend (Fig. 6.21), there is no significant difference compared to the unstratified sample of OTCM forecasts.

As in previous subgroups, an initial rightward track bias and long-range leftward bias (Fig. 6.23) result in poor CT performance at 24 and 72 h (Fig. 6.22). The OTCM has the best 48 h CT performance of any aid. There is no significant difference between subgroup 4 and total sample AT skill. An initial slow bias followed by a fast long-range bias (Fig. 6.24) results in no AT skill at 24 and 72 h.

2. Analogs (REC and TOTL)

The REC aid has no MFE skill in this subgroup, while the TOTL has short-range skill (2 - 4%), and no long-range skill. As in subgroup 3, the REC has a reduction in SX errors compared to the unstratified sample, while no significant difference is observed in TOTL systematic error trend (Fig. 6.21).

The CT/AT M-score variation with time (Fig. 6.22) shows that the REC and TOTL aids are similar to OTCM in the profile trend of their performances. As in previous subgroups, a large REC rightward track bias and TOTL leftward track bias

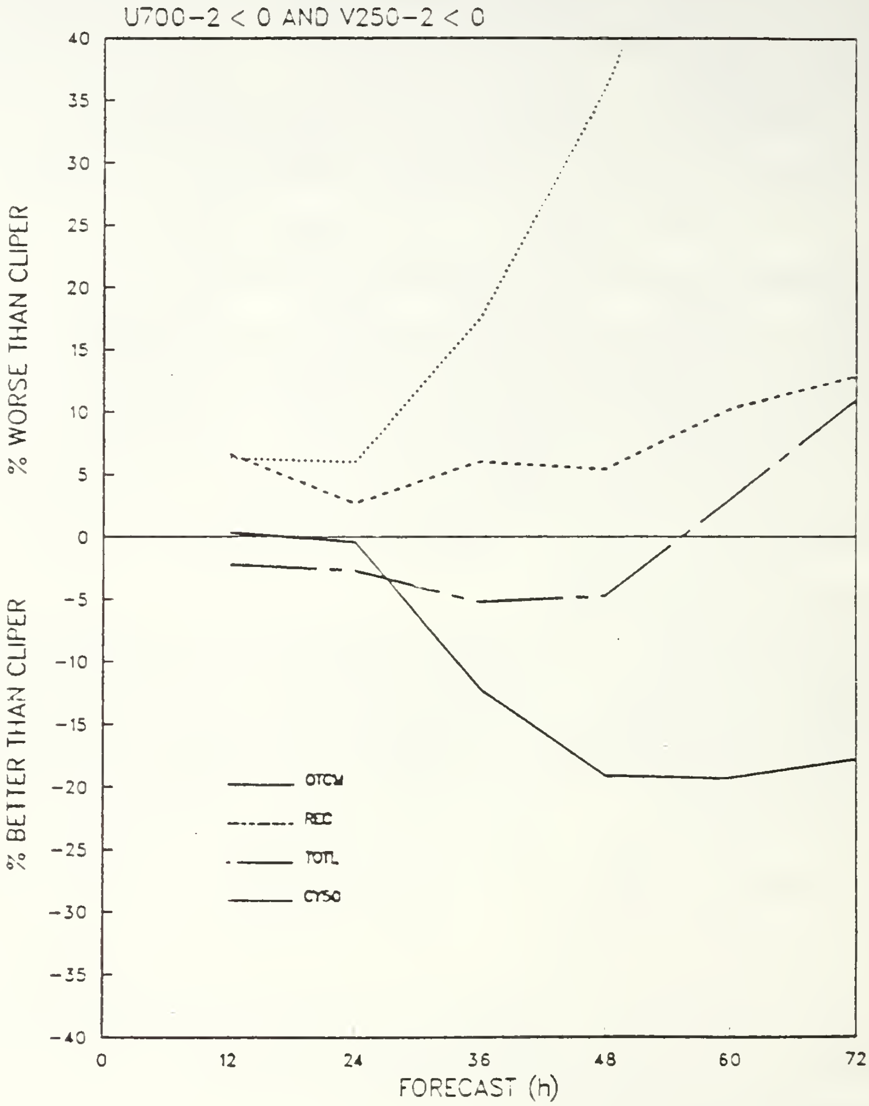

Figure 6.20 As in Fig. 6.2, except for subgroup 4.

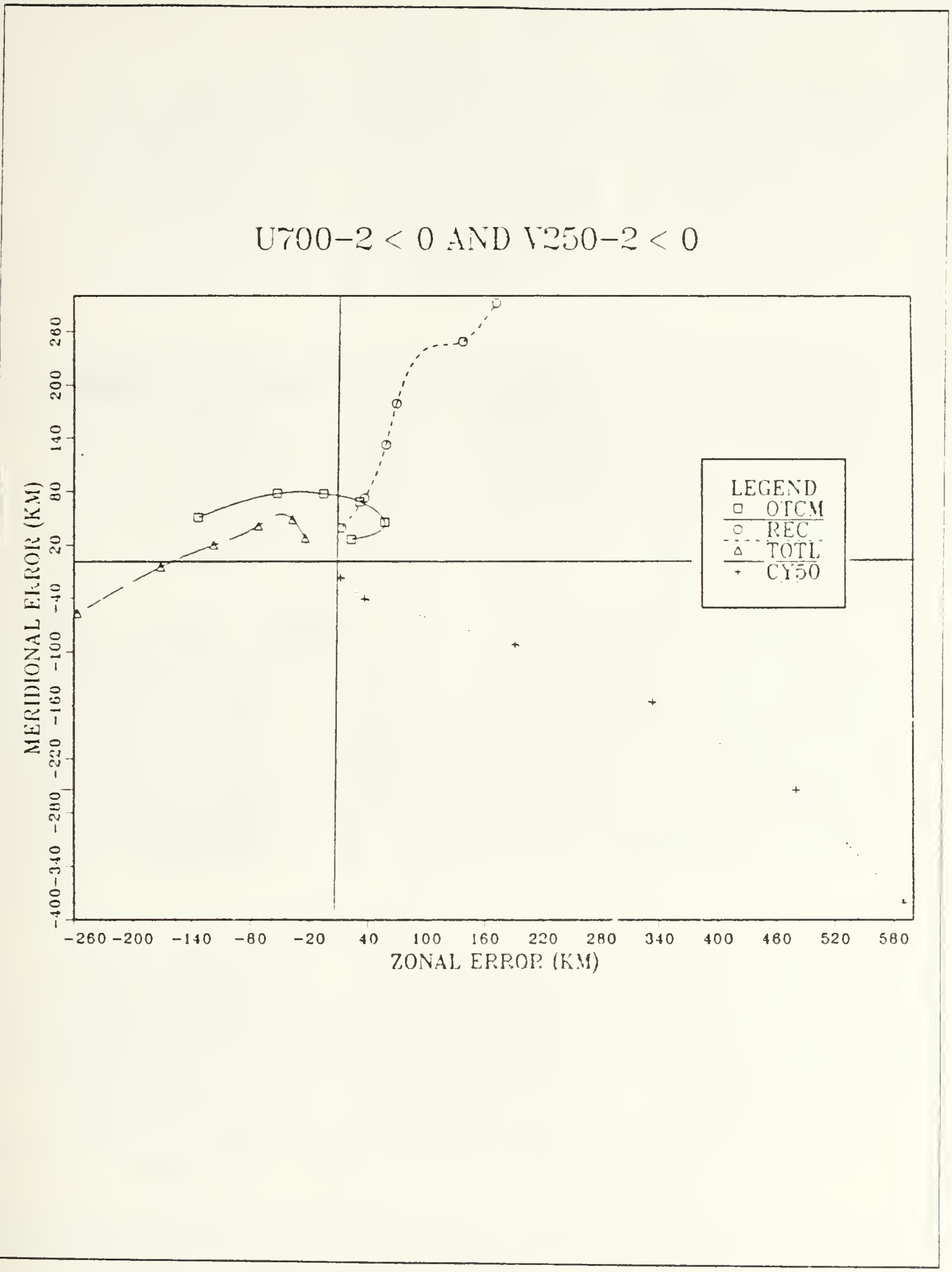

Figure 6.21 As in Fig. 6.3, except for subgroup 4.

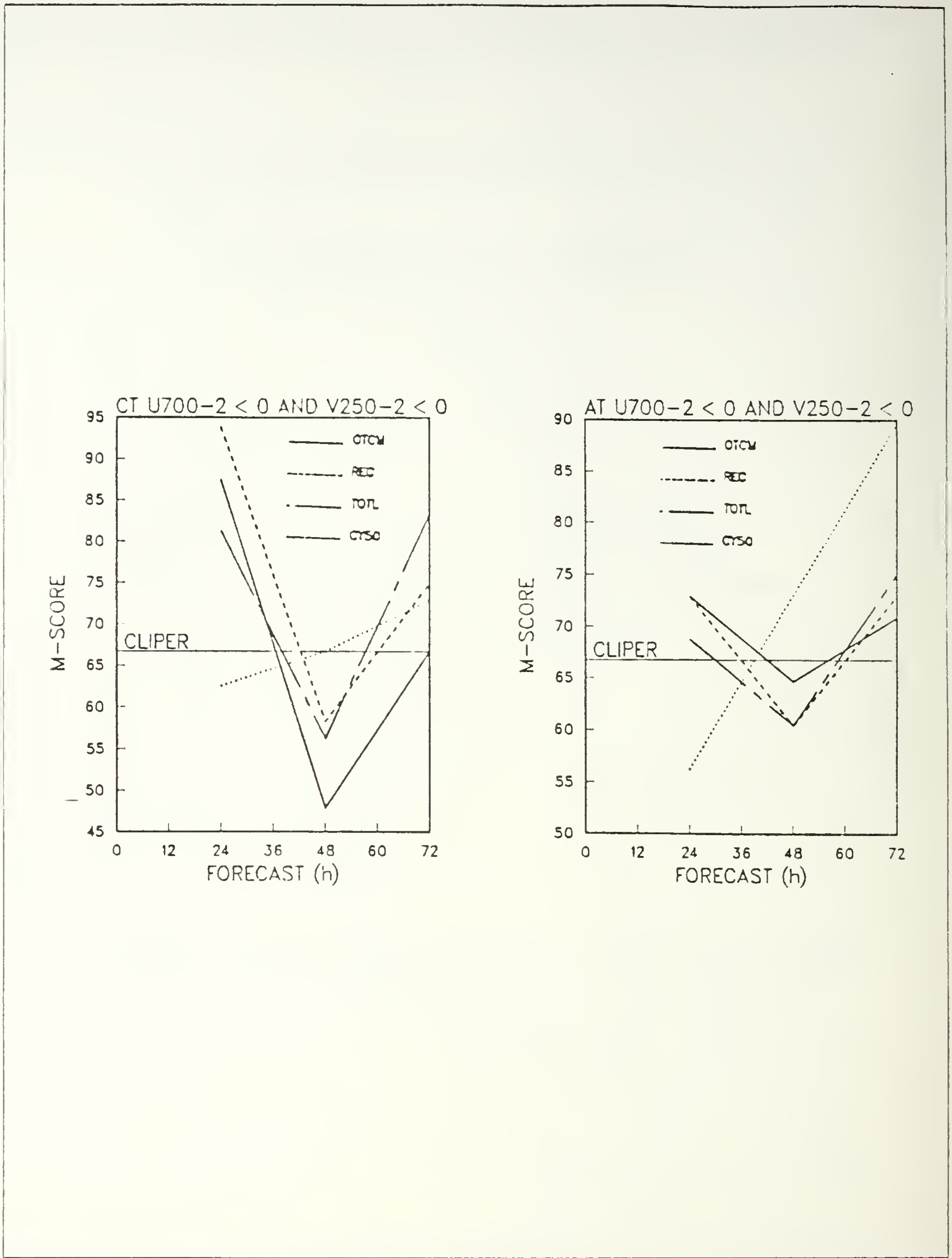

Figure 6.22 As in Fig. 6.4, except for subgroup 4.

24 h — OTCM

Best Track	%0	%1	%2
L	12.5	62.5	25.0
C	13.3	66.7	
R	47.1	41.2	11.8
Total	25.0	62.5	12.5

M Score = 87.5

24 h — REC

Best Track	%0	%1	%2
L	6.3	37.5	56.3
C	13.3	86.7	
R	52.9	47.1	0.0
Total	25.0	56.3	18.8

M Score = 93.8

24 h — TOTL

Best Track	%0	%1	%2
L	18.8	62.5	18.8
C	46.7	53.3	
R	29.4	52.9	17.6
Total	31.3	56.3	12.5

M Score = 81.3

24 h — CY50

Best Track	%0	%1	%2
L	62.5	12.5	25.0
C	60.0	40.0	
R	41.2	35.3	23.5
Total	54.2	29.2	16.7

M Score = 62.5

48 h — OTCM

Best Track	%0	%1	%2
L	50.0	50.0	0.0
C	70.8	29.2	
R	25.0	50.0	25.0
Total	56.3	39.6	4.2

M Score = 47.9

48 h — REC

Best Track	%0	%1	%2
L	12.5	81.3	6.3
C	79.2	20.8	
R	0.0	99.9	0.0
Total	43.8	54.2	2.1

M Score = 58.3

48 h — TOTL

Best Track	%0	%1	%2
L	56.3	43.8	0.0
C	62.5	37.5	
R	0.0	62.5	37.5
Total	50.0	43.8	6.3

M Score = 56.3

48 h — CY50

Best Track	%0	%1	%2
L	37.5	25.0	37.5
C	62.5	37.5	
R	25.0	62.5	12.5
Total	47.9	37.5	14.6

M Score = 66.7

72 h — OTCM

Best Track	%0	%1	%2
L	56.3	37.5	6.3
C	50.0	50.0	
R	37.5	25.0	37.5
Total	47.9	37.5	14.6

M Score = 66.7

72 h — REC

Best Track	%0	%1	%2
L	18.8	50.0	31.3
C	62.5	37.5	
R	43.8	37.5	18.8
Total	41.7	41.7	16.7

M Score = 75.0

72 h — TOTL

Best Track	%0	%1	%2
L	81.3	18.8	0.0
C	37.5	62.5	
R	6.3	18.8	75.0
Total	41.7	33.3	25.0

M Score = 83.3

72 h — CY50

Best Track	%0	%1	%2
L	50.0	25.0	25.0
C	31.3	68.8	
R	50.0	25.0	25.0
Total	43.8	39.6	16.7

M Score = 72.9

Figure 6.23 As in Fig. 6.8, except for subgroup 4.

24 h — OTCM

Best Track	%0	%1	%2
S	62.5	31.3	6.3
C	18.8	81.3	
F	43.8	18.8	37.5
Total	41.7	43.8	14.6

M Score = 72.9

24 h — REC

Best Track	%0	%1	%2
S	18.8	68.8	12.5
C	56.3	43.8	
F	31.3	56.3	12.5
Total	35.4	56.3	8.3

M Score = 72.9

24 h — TOTL

Best Track	%0	%1	%2
S	18.8	37.5	43.8
C	56.3	43.8	
F	68.8	25.0	6.3
Total	47.9	35.4	16.7

M Score = 68.7

24 h — CY50

Best Track	%0	%1	%2
S	50.0	43.8	6.3
C	31.3	68.8	
F	62.5	31.3	6.3
Total	47.9	47.9	4.2

M Score = 56.2

48 h — OTCM

Best Track	%0	%1	%2
S	42.9	35.7	21.4
C	27.8	72.2	
F	68.8	18.8	12.5
Total	45.8	43.8	10.4

M Score = 64.6

48 h — REC

Best Track	%0	%1	%2
S	14.3	42.9	42.9
C	50.0	50.0	
F	87.5	12.5	0.0
Total	52.1	35.4	12.5

M Score = 60.4

48 h — TOTL

Best Track	%0	%1	%2
S	35.7	28.6	35.7
C	27.8	72.2	
F	87.5	12.5	0.0
Total	50.0	39.6	10.4

M Score = 60.4

48 h — CY50

Best Track	%0	%1	%2
S	71.4	21.4	7.1
C	22.2	77.8	
F	31.3	37.5	31.3
Total	39.6	47.9	12.5

M Score = 72.9

72 h — OTCM

Best Track	%0	%1	%2
S	40.0	20.0	40.0
C	29.4	70.6	
F	68.8	18.8	12.5
Total	45.8	37.5	16.7

M Score = 70.8

72 h — REC

Best Track	%0	%1	%2
S	20.0	33.3	46.7
C	35.3	64.7	
F	75.0	18.8	6.3
Total	43.8	39.6	16.7

M Score = 72.9

72 h — TOTL

Best Track	%0	%1	%2
S	33.3	40.0	26.7
C	35.3	64.7	
F	56.3	18.8	25.0
Total	41.7	41.7	16.7

M Score = 75.0

72 h — CY50

Best Track	%0	%1	%2
S	80.0	6.7	13.3
C	0.0	99.9	
F	25.0	18.8	56.3
Total	33.3	43.8	22.9

M Score = 89.6

Figure 6.24 As in Fig. 6.9, except for subgroup 4.

(Fig. 6.23) results in no CT skill at 24 and 72 h for both aids. Similarly, fast biases in both aids (Fig. 6.24) result in no AT skill at 24 and 72 h (especially at 72 h). Thus, both analogs are unable to predict the possibly slower and more right-turning storms in subgroup 4, except at 48 h.

3. Steering (CY50)

The CY50 aid demonstrates no skill in this subgroup (Fig. 6.20). As in previous subgroups, a southeastward bias is responsible for this poor performance (Fig. 6.21). Furthermore, the CY50 bias is the largest of any subgroup. Thus, no skill is shown in either path or speed prediction beyond 24 h (Fig. 6.22).

F. SUMMARY

The 2 X 2 EOF synoptic classification provides a distinct set of subgroups for the evaluation of objective aid performance. The EOFS derived from the environmental wind field provide a physically realistic depiction of different synoptic conditions associated with tropical cyclone motion. Mode 2 of the 700 mb zonal flow indicates the direction and strength of the zonal steering flow. Mode 2 of the 250 mb meridional flow describes the mid-latitude troughs and ridges to the north of the tropical cyclone.

Subgroup 1. In this subgroup, the low-level easterlies advect the cyclone towards the ridge to the west which results in the lowest northward motion of any subgroup. The OTCM has its worst performance in this subgroup with no skill demonstrated in any forecast period. The only CT skill shown is by REC and CY50 at 48 h , and AT skill by TOTL and CY50 at 24 h. There is no skill in either AT or CT prediction by any aid at 72 h.

Subgroup 2. The low-level westerlies retard the westward motion of cyclones and slightly increase the northward motion compared to subgroup 1. The OTCM has no skill at 24 h, CT and AT skill at 48 h, and only CT skill at 72 h. Both REC and TOTL have CT skill at 24 h. Only TOTL has CT skill at 48 h and AT skill at 72 h. The CY50 aid only has CT skill at 24 h.

Subgroup 3. The low-level easterlies advect the cyclones toward the trough to the west which results in higher westward motion compared to subgroup 2, and greater northward motion compared to subgroups 1 and 2. The OTCM has its best performance in this subgroup with CT and AT skill at all forecast periods. The REC has AT skill at 24 h, CT skill at 48 h and no skill at 72 h. TOTL has AT skill at 24 h, no skill at 48 h and AT skill at 72 h. The CY50 has no AT or CT skill in this subgroup.

Subgroup 4. As in subgroup 2, the low-level westerlies retard the westward motion of cyclones. However, the northward motion is similar to subgroup 3. The OTCM has no skill at 24 h, CT and AT skill at 48 h and no skill at 72 h. Both the REC and TOTL have no skill at 24 h, CT and AT skill at 48 h and no skill at 72 h. The CY50 has CT and AT skill at 24 h and no skill at 48 and 72 h.

VII. CONCLUSIONS

1. Summary

The performance of four western North Pacific Ocean objective aids (OTCM, REC, TOTL, CY50) has been evaluated using various error statistics. Although mean forecast error (MFE) is useful as an absolute measure, it does not provide an assessment of skill. Therefore, the western Pacific CLIPER is used as a normalizer, or no-skill model, to provide a benchmark to measure the skills of other objective techniques. The MFE results show the OTCM is the best overall objective forecast aid, especially in the long-range forecasts. The analogs REC and TOTL show no significant MFE skill with respect to CLIPER in short- to mid-range forecasts, and usually no skill in the long-range forecast. The CY50 usually has only 24 h MFE skill. Because the MFE does not provide any direction information, zonal and meridional systematic errors are calculated as a method of introducing directionality. The systematic error statistics reveal distinct biases for each objective aid: 1) OTCM (short-range northeastward and long-range westward); 2) REC (northeastward); 3) TOTL (westward); and 4) CY50 (southeastward).

Because the largest forecast errors are associated with cyclone turning motion, cross-track (CT) and along-track (AT) components are calculated in terms of left (L), straight (C) and right (R) turning cyclones, and slow (S), central (C) and fast (F) moving categories relative to the CLIPER track. The results are consistent with systematic error biases: 1) OTCM (short-term rightward/slow and long-term leftward/fast); 2) REC (rightward/fast); 3) TOTL (leftward/fast); and 4) CY50 (rightward/slow). The biases in the OTCM may be a result of a pre-processing technique that attempts to correct the initial bias, but overcompensates in the long range. The REC bias may be caused by its selection of only recurving analogs, whereas the selection of analogs from the total sample (TOTL) results in a leftward bias for the recurving storms that are included. The rightward/slow CY50 bias may result from the tendency for western north Pacific cyclone motion to be left-of-track and faster than the 500 mb steering flow (beta-effect).

The stratification of error statistics by storm-related and synoptic parameters provided distinct conditions associated with tropical cyclone motion. These characteristics are summarized in terms of skill in path (CT) or speed (AT) prediction relative to a CLIPER forecast at 24, 48 and 72 h in Tables 1 - 3, respectively.

Dynamical model (OTCM). Consistent with the result of previous studies (Tsui, 1984; Elsberry and Peak, 1986), the OTCM has the best overall mid-range (Table 2) and long-range (Table 3) performance as a result of superior path prediction skill. The 24 h OTCM performance (Table 1) is poor relative to a CLIPER forecast as a result of an initial rightward/slow bias. A pre-processing technique corrects some of this intial bias and gives the OTCM excellent mid- and long-range skill. However, overcompensation by this technique may cause the long-range leftward/fast bias that contributes to the poor performance on north zone, western area and medium size cyclones.

Analogs (REC and TOTL). The REC rightward track bias due to selection of only recurving analogs causes large errors in forecasting left-turning and straight-moving storms. With the exception of path skill on medium size storms, REC has no long-range prediction skill (Table 3) relative to a CLIPER forecast.

The selection of analogs from the total sample (TOTL) results in errors due to missed recurvature forecasts (westward bias). However, the selection of both fast and slow analogs results in superior speed prediction skill, especially at 48 h (Table 2). The superior peformance of CLIPER relative to TOTL indicates a problem in the use of the analog scheme as CLIPER and TOTL are based on similar data bases.

Steering (CY50). Although CY50 is the best aid for short-range forecasts (Table 1), a significant decline in skill is observed after 24 h. Without the physics of the OTCM or the climatology influence in the analog techniques, the CY50 becomes the worst aid for mid- to long-range forecasting.

2. Recommendations for research

The following recommendations for future research are suggested:

1) MFE (normalized by CLIPER), systematic and CT/AT error statistics should be calculated on other objective aids in operational use or undergoing testing and evaluation. The results could be published in the JTWC Annual Tropical Cyclone Report (ATCR).

2) Larger samples are needed for additional stratifications by storm-related and synoptic parameters.

3) The environmental description in terms of the complete set of EOF coefficients provides a quantitative stratification relative to all of the synoptic features, rather than just the subtropical ridge (Xu and Gray, 1982). However, only two of the EOF coefficients have been used here. Some type of "cluster analysis" of more EOF coefficients into distinct synoptic patterns (a map typing) would be useful.

TABLE 1

SUMMARY OF OBJECTIVE AID 24 H PERFORMANCE

	OTCM	REC	TOTL	CY50
LATITUDE				
North	P			P
Central				
South	P			S
LONGITUDE				
Western	S	S		P
Middle			S	P
Eastern				P/S
INTENSITY				
Intense	S			P
Moderate	P		S	P
Weak				P/S
12-Hour IC				
Weakening				P/S
Intensifying		S		P
Rapidly inten.				P/S
SIZE				
Large			S	S
Medium				P/S
Small				P/S
SYNOPTIC				
subgroup 1			S	S
subgroup 2		P	P	P
subgroup 3	P/S	S	S	
subgroup 4				P/S

P = Path skill, S = Speed skill, N = No skill

TABLE 2
SUMMARY OF OBJECTIVE AID 48 H PERFORMANCE

	OTCM	REC	TOTL	CY50
LATITUDE				
North				P
Central	P	S		
South	P/S			
LONGITUDE				
Western			P	
Middle	P/S			
Eastern	P		S	
INTENSITY				
Intense	P/S			
Moderate	P	S	S	
Weak	P		P/S	
12-Hour IC				
Weakening	S		S	P
Intensifying	P	S		
Rapidly inten.	P/S			
SIZE				
Large	P/S			
Medium	S	P		
Small	P	S		
SYNOPTIC				
subgroup 1		P		P
subgroup 2	P/S		P	
subgroup 3	P/S	P		
subgroup 4	P/S	P/S	P/S	

P = Path skill, S = Speed skill, = No skill

TABLE 3

SUMMARY OF OBJECTIVE AID 72 H PERFORMANCE

	OTCM	REC	TOTL	CY50
LATITUDE				
North			S	P
Central	P		S	
South	P		S	
LONGITUDE				
Western				
Middle	S			P
Eastern	P		S	
INTENSITY				
Intense	S			
Moderate	P		S	
Weak	P		S	
12-Hour IC				
Weakening			S	P
Intensifying	P		S	
Rapidly inten.	P/S			
SIZE				
Large	P/S			
Medium		P	S	
Small	P		S	
SYNOPTIC				
subgroup 1				
subgroup 2	P		S	
subgroup 3	P/S		S	
subgroup 4				

P = Path skill, S = Speed skill, = No skill

APPENDIX A

STORM-RELATED PARAMETER PERCENTAGE OF CLASS ERROR TABLES

Each table in this appendix contains three colums which correpond to different values of a storm-related parameter. Each column contains a 3 X 3 table of the percentage of zero-, one- and two- class errors. The numbers in the left column represent "correct" forecasts and are referred to as zero-class errors. The two-class errors consist of objective aid forecasts on the opposite side of the CLIPER track compared to the best track. These errors are located in the right column. The center column contains one-class errors in which the objective aid forecast is displaced only one tercile from the best track. The lower portion of the table summarizes the percentage of class errors for each category (L, C and R or S, C and F). An "M-score" is also provided for each forecast period. The M-score is a linear measure which penalizes an objective aid more (twice) for having two-class errors ($M = V + 2W$), where U, V and W are the percentages of the zero-, one- and two- class errors ($U + V + W = 100\%$).

24 h — OTCM

Best Track	%0	%1	%2
L	38.2	47.1	14.7
C	48.6	51.4	
R	67.6	23.5	8.8
Total	51.5	40.8	7.8

M Score = 56.3

24 h — REC

Best Track	%0	%1	%2
L	17.6	47.1	35.3
C	25.7	74.3	
R	67.6	26.5	5.9
Total	36.9	49.5	13.6

M Score = 76.7

24 h — TOTL

Best Track	%0	%1	%2
L	41.2	44.1	14.7
C	40.0	60.0	
R	35.3	52.9	11.8
Total	38.8	52.4	8.7

M Score = 69.9

24 h — CY50

Best Track	%0	%1	%2
L	82.4	8.8	8.8
C	45.7	54.3	
R	29.4	50.0	20.6
Total	52.4	37.9	9.7

M Score = 57.3

48 h — OTCM

Best Track	%0	%1	%2
L	79.4	20.6	0.0
C	60.0	40.0	
R	52.9	47.1	0.0
Total	64.1	35.9	0.0

M Score = 35.9

48 h — REC

Best Track	%0	%1	%2
L	26.5	44.1	29.4
C	22.9	77.1	
R	82.4	11.8	5.9
Total	43.7	44.7	11.7

M Score = 68.0

48 h — TOTL

Best Track	%0	%1	%2
L	61.8	38.2	0.0
C	54.3	45.7	
R	20.6	73.5	5.9
Total	45.6	52.4	1.9

M Score = 56.3

48 h — CY50

Best Track	%0	%1	%2
L	67.6	11.8	20.6
C	31.4	68.6	
R	26.5	61.8	11.8
Total	41.7	47.6	10.7

M Score = 68.9

72 h — OTCM

Best Track	%0	%1	%2
L	81.8	18.2	0.0
C	44.4	55.6	
R	41.2	58.8	0.0
Total	55.3	44.7	0.0

M Score = 44.7

72 h — REC

Best Track	%0	%1	%2
L	30.3	42.4	27.3
C	38.9	61.1	
R	88.2	5.9	5.9
Total	52.4	36.9	10.7

M Score = 58.3

72 h — TOTL

Best Track	%0	%1	%2
L	51.5	45.5	3.0
C	55.6	44.4	
R	23.5	67.6	8.8
Total	43.7	52.4	3.9

M Score = 60.2

72 h — CY50

Best Track	%0	%1	%2
L	57.6	12.1	30.3
C	27.8	72.2	
R	29.4	55.9	14.7
Total	37.9	47.6	14.6

M Score = 76.7

Figure A.1 Cross-track (CT) percentages of 0-, 1- and 2-class errors of the latitude < 13°N subsample for each tercile of the best track distribution relative to CLIPER (L-left, C-Center, R-right).

24 h — OTCM

Best Track	%0	%1	%2
S	64.7	26.5	8.8
C	28.6	71.4	
F	55.9	14.7	29.4
Total	49.5	37.9	12.6

M Score = 63.1

24 h — REC

Best Track	%0	%1	%2
S	41.2	55.9	2.9
C	45.7	54.3	
F	29.4	61.8	8.8
Total	38.8	57.3	3.9

M Score = 65.0

24 h — TOTL

Best Track	%0	%1	%2
S	20.6	73.5	5.9
C	62.9	37.1	
F	47.1	47.1	5.9
Total	43.7	52.4	3.9

M Score = 60.2

24 h — CY50

Best Track	%0	%1	%2
S	58.8	35.3	5.9
C	28.6	71.4	
F	76.5	14.7	8.8
Total	54.4	40.8	4.9

M Score = 50.5

48 h — OTCM

Best Track	%0	%1	%2
S	58.8	26.5	14.7
C	35.3	64.7	
F	71.4	11.4	17.1
Total	55.3	34.0	10.7

M Score = 55.3

48 h — REC

Best Track	%0	%1	%2
S	32.4	50.0	17.6
C	29.4	70.6	
F	71.4	22.9	5.7
Total	44.7	47.6	7.8

M Score = 63.1

48 h — TOTL

Best Track	%0	%1	%2
S	35.3	35.3	29.4
C	35.3	64.7	
F	82.9	14.3	2.9
Total	51.5	37.9	10.7

M Score = 59.2

48 h — CY50

Best Track	%0	%1	%2
S	79.4	14.7	5.9
C	23.5	76.5	
F	57.1	20.0	22.9
Total	53.4	36.9	9.7

M Score = 56.3

72 h — OTCM

Best Track	%0	%1	%2
S	44.1	35.3	20.6
C	22.9	77.1	
F	73.5	20.6	5.9
Total	46.6	44.7	8.7

M Score = 62.1

72 h — REC

Best Track	%0	%1	%2
S	44.1	41.2	14.7
C	28.6	71.4	
F	70.6	26.5	2.9
Total	47.6	46.6	5.8

M Score = 58.3

72 h — TOTL

Best Track	%0	%1	%2
S	50.0	26.5	23.5
C	42.9	57.1	
F	70.6	26.5	2.9
Total	54.4	36.9	8.7

M Score = 54.4

72 h — CY50

Best Track	%0	%1	%2
S	79.4	11.8	8.8
C	11.4	88.6	
F	50.0	23.5	26.5
Total	46.6	41.7	11.7

M Score = 65.0

Figure A.2 As in Fig. A.1, except for along-track (AT) components (S-slow, C-center, F-fast relative to CLIPER) for latitude < 13°N subsample.

24 h — OTCM

Best Track	%0	%1	%2
L	33.3	33.3	33.3
C	14.0	86.0	
R	80.5	12.2	7.3
Total	42.1	44.4	13.5

M Score = 71.4

24 h — REC

Best Track	%0	%1	%2
L	11.9	54.8	33.3
C	34.9	65.1	
R	68.3	31.7	0.0
Total	38.1	50.8	11.1

M Score = 73.0

24 h — TOTL

Best Track	%0	%1	%2
L	26.2	57.1	16.7
C	58.1	41.9	
R	36.6	53.7	9.8
Total	40.5	50.8	8.7

M Score = 68.3

24 h — CY50

Best Track	%0	%1	%2
L	52.4	35.7	11.9
C	41.9	58.1	
R	24.4	46.3	29.3
Total	39.7	46.8	13.5

M Score = 73.8

48 h — OTCM

Best Track	%0	%1	%2
L	57.1	33.3	9.5
C	35.7	64.3	
R	42.9	35.7	21.4
Total	45.2	44.4	10.3

M Score = 65.1

48 h — REC

Best Track	%0	%1	%2
L	19.0	50.0	31.0
C	35.7	64.3	
R	64.3	31.0	4.8
Total	39.7	48.4	11.9

M Score = 72.2

48 h — TOTL

Best Track	%0	%1	%2
L	59.5	33.3	7.1
C	64.3	35.7	
R	2.4	69.0	28.6
Total	42.1	46.0	11.9

M Score = 69.8

48 h — CY50

Best Track	%0	%1	%2
L	52.4	14.3	33.3
C	31.0	69.0	
R	33.3	47.6	19.0
Total	38.9	43.7	17.5

M Score = 78.6

72 h — OTCM

Best Track	%0	%1	%2
L	52.4	40.5	7.1
C	38.1	61.9	
R	47.6	21.4	31.0
Total	46.0	41.3	12.7

M Score = 66.7

72 h — REC

Best Track	%0	%1	%2
L	14.3	38.1	47.6
C	45.2	54.8	
R	71.4	21.4	7.1
Total	43.7	38.1	18.3

M Score = 74.6

72 h — TOTL

Best Track	%0	%1	%2
L	52.4	38.1	9.5
C	40.5	59.5	
R	7.1	40.5	52.4
Total	33.3	46.0	20.6

M Score = 87.3

72 h — CY50

Best Track	%0	%1	%2
L	50.0	23.8	26.2
C	21.4	78.6	
R	40.5	42.9	16.7
Total	37.3	48.4	14.3

M Score = 77.0

Figure A.3 As in Fig. A.1, except for latitudes between 13°N and 17°N.

24 h OTCM

Best Track	%0	%1	%2
S	61.9	38.1	0.0
C	28.6	71.4	
F	26.2	31.0	42.9
Total	38.9	46.8	14.3

M Score = 75.4

24 h REC

Best Track	%0	%1	%2
S	23.8	64.3	11.9
C	57.1	42.9	
F	14.3	73.8	11.9
Total	31.7	60.3	7.9

M Score = 76.2

24 h TOTL

Best Track	%0	%1	%2
S	4.8	76.2	19.0
C	57.1	42.9	
F	40.5	57.1	2.4
Total	34.1	58.7	7.1

M Score = 73.0

24 h CY50

Best Track	%0	%1	%2
S	61.9	26.2	11.9
C	26.2	73.8	
F	33.3	28.6	38.1
Total	40.5	42.9	16.7

M Score = 76.2

48 h OTCM

Best Track	%0	%1	%2
S	47.6	45.2	7.1
C	52.4	47.6	
F	38.1	38.1	23.8
Total	46.0	43.7	10.3

M Score = 64.3

48 h REC

Best Track	%0	%1	%2
S	26.2	69.0	4.8
C	78.6	21.4	
F	33.3	61.9	4.8
Total	46.0	50.8	3.2

M Score = 57.1

48 h TOTL

Best Track	%0	%1	%2
S	16.7	71.4	11.9
C	81.0	19.0	
F	38.1	61.9	0.0
Total	45.2	50.8	4.0

M Score = 58.7

48 h CY50

Best Track	%0	%1	%2
S	69.0	11.9	19.0
C	26.2	73.8	
F	14.3	35.7	50.0
Total	36.5	40.5	23.0

M Score = 86.5

72 h OTCM

Best Track	%0	%1	%2
S	45.2	35.7	19.0
C	37.2	62.8	
F	39.0	48.8	12.2
Total	40.5	49.2	10.3

M Score = 69.8

72 h REC

Best Track	%0	%1	%2
S	28.6	42.9	28.6
C	44.2	55.8	
F	46.3	48.8	4.9
Total	39.7	49.2	11.1

M Score = 71.4

72 h TOTL

Best Track	%0	%1	%2
S	16.7	69.0	14.3
C	55.8	44.2	
F	53.7	43.9	2.4
Total	42.1	52.4	5.6

M Score = 63.5

72 h CY50

Best Track	%0	%1	%2
S	64.3	9.5	26.2
C	4.7	95.3	
F	9.8	26.8	63.4
Total	26.2	44.4	29.4

M Score = 102.8

Figure A.4 As in Fig. A.2, except for latitudes between 13°N and 17°N.

24 h — OTCM (Best Track)

	%0	%1	%2
L	33.3	40.5	26.2
C	40.5	59.5	
R	48.8	27.9	23.3
Total	40.9	42.5	16.5

M Score = 75.6

24 h — REC (Best Track)

	%0	%1	%2
L	9.5	61.9	28.6
C	69.0	31.0	
R	30.2	65.1	4.7
Total	36.2	52.8	11.0

M Score = 74.8

24 h — TOTL (Best Track)

	%0	%1	%2
L	40.5	54.8	4.8
C	40.5	59.5	
R	7.0	39.5	53.5
Total	29.1	51.2	19.7

M Score = 90.6

24 h — CY50 (Best Track)

	%0	%1	%2
L	57.1	33.3	9.5
C	59.5	40.5	
R	46.5	46.5	7.0
Total	54.3	40.2	5.5

M Score = 51.2

48 h — OTCM (Best Track)

	%0	%1	%2
L	54.8	26.2	19.0
C	30.2	69.8	
R	31.0	35.7	33.3
Total	38.6	44.1	17.3

M Score = 78.7

48 h — REC (Best Track)

	%0	%1	%2
L	14.3	54.8	31.0
C	51.2	48.8	
R	19.0	73.8	7.1
Total	28.3	59.1	12.6

M Score = 84.3

48 h — TOTL (Best Track)

	%0	%1	%2
L	73.8	26.2	0.0
C	20.9	79.1	
R	2.4	26.2	71.4
Total	32.3	44.1	23.6

M Score = 91.3

48 h — CY50 (Best Track)

	%0	%1	%2
L	33.3	42.9	23.8
C	65.1	34.9	
R	52.4	45.2	2.4
Total	50.4	40.9	8.7

M Score = 58.3

72 h — OTCM (Best Track)

	%0	%1	%2
L	59.5	16.7	23.8
C	33.3	66.7	
R	30.2	30.2	39.5
Total	40.9	37.8	21.3

M Score = 80.3

72 h — REC (Best Track)

	%0	%1	%2
L	26.2	38.1	35.7
C	57.1	42.9	
R	23.3	48.8	27.9
Total	35.4	43.3	21.3

M Score = 85.8

72 h — TOTL (Best Track)

	%0	%1	%2
L	85.7	11.9	2.4
C	7.1	92.9	
R	0.0	7.0	93.0
Total	30.7	37.0	32.3

M Score = 100.0

72 h — CY50 (Best Track)

	%0	%1	%2
L	26.2	38.1	35.7
C	59.5	40.5	
R	65.1	32.6	2.3
Total	50.4	37.0	12.6

M Score = 62.2

Figure A.5 As in Fig. A.1, except for latitude > 17°N.

24 h OTCM

Best Track	%0	%1	%2
S	52.4	40.5	7.1
C	45.2	54.8	
F	48.8	34.9	16.3
Total	48.8	43.3	7.9

M Score = 59.1

24 h REC

Best Track	%0	%1	%2
S	23.8	50.0	26.2
C	54.8	45.2	
F	48.8	39.5	11.6
Total	42.5	44.9	12.6

M Score = 70.1

24 h TOTL

Best Track	%0	%1	%2
S	21.4	40.5	38.1
C	35.7	64.3	
F	67.4	32.6	0.0
Total	41.7	45.7	12.6

M Score = 70.9

24 h CY50

Best Track	%0	%1	%2
S	42.9	38.1	19.0
C	40.5	59.5	
F	44.2	41.9	14.0
Total	42.5	46.5	11.0

M Score = 68.5

48 h OTCM

Best Track	%0	%1	%2
S	33.3	38.1	28.6
C	33.3	66.7	
F	60.5	27.9	11.6
Total	42.5	44.1	13.4

M Score = 70.9

48 h REC

Best Track	%0	%1	%2
S	11.9	35.7	52.4
C	42.9	57.1	
F	62.8	25.6	11.6
Total	39.4	39.4	21.3

M Score = 81.9

48 h TOTL

Best Track	%0	%1	%2
S	23.8	40.5	35.7
C	38.1	61.9	
F	67.4	27.9	4.7
Total	43.3	43.3	13.4

M Score = 70.1

48 h CY50

Best Track	%0	%1	%2
S	81.0	14.3	4.8
C	21.4	78.6	
F	23.3	25.6	51.2
Total	41.7	39.4	18.9

M Score = 77.2

72 h OTCM

Best Track	%0	%1	%2
S	21.4	40.5	38.1
C	34.9	65.1	
F	59.5	23.8	16.7
Total	38.6	43.3	18.1

M Score = 79.5

72 h REC

Best Track	%0	%1	%2
S	14.3	40.5	45.2
C	48.8	51.2	
F	59.5	21.4	19.0
Total	40.9	37.8	21.3

M Score = 80.3

72 h TOTL

Best Track	%0	%1	%2
S	52.4	38.1	9.5
C	44.2	55.8	
F	31.0	52.4	16.7
Total	42.5	48.8	8.7

M Score = 66.1

72 h CY50

Best Track	%0	%1	%2
S	95.2	0.0	4.8
C	25.6	74.4	
F	19.0	35.7	45.2
Total	46.5	37.0	16.5

M Score = 70.1

Figure A.6 As in Fig. A.2, except for latitude > 17°N.

24 h — OTCM

Best Track	%0	%1	%2
L	35.1	32.4	32.4
C	20.5	79.5	
R	78.4	16.2	5.4
Total	44.2	43.4	12.4

M Score = 68.1

24 h — REC

Best Track	%0	%1	%2
L	21.6	21.6	56.8
C	12.8	87.2	
R	75.7	24.3	0.0
Total	36.3	45.1	18.6

M Score = 82.3

24 h — TOTL

Best Track	%0	%1	%2
L	40.5	35.1	24.3
C	64.1	35.9	
R	29.7	54.1	16.2
Total	45.1	41.6	13.3

M Score = 68.1

24 h — CY50

Best Track	%0	%1	%2
L	45.9	35.1	18.9
C	41.0	59.0	
R	54.1	27.0	18.9
Total	46.9	40.7	12.4

M Score = 65.5

48 h — OTCM

Best Track	%0	%1	%2
L	51.4	32.4	16.2
C	33.3	66.7	
R	45.9	48.6	5.4
Total	43.4	49.6	7.1

M Score = 63.7

48 h — REC

Best Track	%0	%1	%2
L	24.3	35.1	40.5
C	23.1	76.9	
R	59.5	37.8	2.7
Total	35.4	50.4	14.2

M Score = 78.8

48 h — TOTL

Best Track	%0	%1	%2
L	78.4	18.9	2.7
C	74.4	25.6	
R	0.0	64.9	35.1
Total	51.3	36.3	12.4

M Score = 61.1

48 h — CY50

Best Track	%0	%1	%2
L	29.7	29.7	40.5
C	41.0	59.0	
R	59.5	32.4	8.1
Total	43.4	40.7	15.9

M Score = 72.6

72 h — OTCM

Best Track	%0	%1	%2
L	62.2	18.9	18.9
C	23.7	76.3	
R	39.5	36.8	23.7
Total	41.6	44.2	14.2

M Score = 72.6

72 h — REC

Best Track	%0	%1	%2
L	27.0	16.2	56.8
C	28.9	71.1	
R	71.1	15.8	13.2
Total	42.5	34.5	23.0

M Score = 80.5

72 h — TOTL

Best Track	%0	%1	%2
L	78.4	18.9	2.7
C	31.6	68.4	
R	0.0	21.1	78.9
Total	36.3	36.3	27.4

M Score = 91.2

72 h — CY50

Best Track	%0	%1	%2
L	21.6	29.7	48.6
C	18.4	81.6	
R	76.3	15.8	7.9
Total	38.9	42.5	18.6

M Score = 79.6

Figure A.7 As in Fig. A.1, except for longitude < 129°E.

24 h OTCM

Best Track	%0	%1	%2
S	64.9	29.7	5.4
C	33.3	66.7	
F	45.9	24.3	29.7
Total	47.8	40.7	11.5

M Score = 63.7

24 h REC

Best Track	%0	%1	%2
S	32.4	54.1	13.5
C	48.7	51.3	
F	56.8	27.0	16.2
Total	46.0	44.2	9.7

M Score = 63.7

24 h TOTL

Best Track	%0	%1	%2
S	8.1	56.8	35.1
C	25.6	74.4	
F	73.0	21.6	5.4
Total	35.4	51.3	13.3

M Score = 77.9

24 h CY50

Best Track	%0	%1	%2
S	51.4	32.4	16.2
C	38.5	61.5	
F	54.1	27.0	18.9
Total	47.8	40.7	11.5

M Score = 63.7

48 h OTCM

Best Track	%0	%1	%2
S	43.2	32.4	24.3
C	36.8	63.2	
F	57.9	21.1	21.1
Total	46.0	38.9	15.0

M Score = 69.0

48 h REC

Best Track	%0	%1	%2
S	27.0	40.5	32.4
C	31.6	68.4	
F	60.5	21.1	18.4
Total	39.8	43.4	16.8

M Score = 77.0

48 h TOTL

Best Track	%0	%1	%2
S	21.6	27.0	51.4
C	31.6	68.4	
F	60.5	34.2	5.3
Total	38.1	43.4	18.6

M Score = 80.5

48 h CY50

Best Track	%0	%1	%2
S	73.0	10.8	16.2
C	23.7	76.3	
F	28.9	36.8	34.2
Total	41.6	41.6	16.8

M Score = 75.2

72 h OTCM

Best Track	%0	%1	%2
S	45.7	14.3	40.0
C	17.1	82.9	
F	54.1	32.4	13.5
Total	38.1	45.1	16.8

M Score = 78.8

72 h REC

Best Track	%0	%1	%2
S	22.9	34.3	42.9
C	34.1	65.9	
F	73.0	10.8	16.2
Total	43.4	38.1	18.6

M Score = 75.2

72 h TOTL

Best Track	%0	%1	%2
S	40.4	22.9	37.1
C	36.6	63.4	
F	54.1	35.1	10.8
Total	43.4	41.6	15.0

M Score = 71.7

72 h CY50

Best Track	%0	%1	%2
S	74.3	2.9	22.9
C	17.1	82.9	
F	35.1	21.6	43.2
Total	40.7	38.1	21.2

M Score = 80.5

Figure A.8 As in Fig. A.2, except for longitude < 129°E.

24 h — OTCM

Best Track	%0	%1	%2
L	50.0	40.5	9.5
C	33.3	66.7	
R	51.2	27.9	20.9
Total	44.9	44.9	10.2

M Score = 65.4

24 h — REC

Best Track	%0	%1	%2
L	9.5	69.0	21.4
C	71.4	28.6	
R	27.9	60.5	11.6
Total	36.2	52.8	11.0

M Score = 74.8

24 h — TOTL

Best Track	%0	%1	%2
L	59.5	31.0	9.5
C	42.9	57.1	
R	7.0	53.5	39.5
Total	36.2	47.2	16.5

M Score = 80.3

24 h — CY50

Best Track	%0	%1	%2
L	76.2	21.4	2.4
C	52.4	47.6	
R	14.0	67.4	18.6
Total	47.2	45.7	7.1

M Score = 59.8

48 h — OTCM

Best Track	%0	%1	%2
L	78.6	19.0	2.4
C	48.8	51.2	
R	50.0	21.4	28.6
Total	59.1	30.7	10.2

M Score = 51.2

48 h — REC

Best Track	%0	%1	%2
L	28.6	40.5	31.0
C	51.2	48.8	
R	21.4	69.0	9.5
Total	33.9	52.8	13.4

M Score = 79.5

48 h — TOTL

Best Track	%0	%1	%2
L	71.4	26.2	2.4
C	25.6	74.4	
R	0.0	35.7	64.3
Total	32.3	45.7	22.0

M Score = 89.8

48 h — CY50

Best Track	%0	%1	%2
L	59.5	23.8	16.7
C	60.5	39.5	
R	16.7	76.2	7.1
Total	45.7	46.5	7.9

M Score = 62.2

72 h — OTCM

Best Track	%0	%1	%2
L	64.3	26.2	9.5
C	45.2	54.8	
R	32.6	32.6	34.9
Total	47.2	37.8	15.0

M Score = 67.7

72 h — REC

Best Track	%0	%1	%2
L	19.0	47.6	33.3
C	57.1	42.9	
R	39.5	46.5	14.0
Total	38.6	45.7	15.7

M Score = 77.2

72 h — TOTL

Best Track	%0	%1	%2
L	71.4	23.8	4.8
C	16.7	83.3	
R	0.0	34.9	65.1
Total	29.1	47.2	23.6

M Score = 94.5

72 h — CY50

Best Track	%0	%1	%2
L	59.5	26.2	14.3
C	64.3	35.7	
R	30.2	55.8	14.0
Total	51.2	39.4	9.4

M Score = 58.3

Figure A.9 As in Fig. A.1, except for longitude between 129 and 140°E.

24 h OTCM

Best Track	%0	%1	%2
S	59.5	38.1	2.4
C	48.8	51.2	
F	42.9	31.0	26.2
Total	50.4	40.2	9.4

M Score = 59.1

24 h REC

Best Track	%0	%1	%2
S	28.6	61.9	9.5
C	72.1	27.9	
F	31.0	54.8	14.3
Total	44.1	48.0	7.9

M Score = 63.8

24 h TOTL

Best Track	%0	%1	%2
S	26.2	59.5	14.3
C	69.8	30.2	
F	57.1	42.9	0.0
Total	51.2	44.1	4.7

M Score = 53.5

24 h CY50

Best Track	%0	%1	%2
S	64.3	28.6	7.1
C	41.9	58.1	
F	42.9	28.6	28.6
Total	49.6	38.6	11.8

M Score = 62.2

48 h OTCM

Best Track	%0	%1	%2
S	52.4	35.7	11.9
C	45.0	55.0	
F	64.4	26.7	8.9
Total	54.3	38.6	7.1

M Score = 52.8

48 h REC

Best Track	%0	%1	%2
S	14.3	45.2	40.5
C	72.5	27.5	
F	62.2	35.6	2.2
Total	49.6	36.2	14.2

M Score = 64.6

48 h TOTL

Best Track	%0	%1	%2
S	28.6	42.9	28.6
C	47.5	52.5	
F	71.1	24.4	4.4
Total	49.6	39.4	11.0

M Score = 61.4

48 h CY50

Best Track	%0	%1	%2
S	83.3	11.9	4.8
C	25.0	75.0	
F	31.1	22.2	46.7
Total	46.5	35.4	18.1

M Score = 71.7

72 h OTCM

Best Track	%0	%1	%2
S	31.0	52.4	16.7
C	34.9	65.1	
F	71.4	16.7	11.9
Total	45.7	44.9	9.5

M Score = 63.8

72 h REC

Best Track	%0	%1	%2
S	23.8	38.1	38.1
C	41.9	58.1	
F	54.8	38.1	7.1
Total	40.2	44.9	15.0

M Score = 74.8

72 h TOTL

Best Track	%0	%1	%2
S	26.2	52.4	21.4
C	39.5	60.5	
F	54.8	33.3	11.9
Total	40.2	48.8	11.0

M Score = 70.9

72 h CY50

Best Track	%0	%1	%2
S	90.5	0.0	9.5
C	14.0	86.0	
F	26.2	11.9	61.9
Total	43.3	33.1	23.6

M Score = 80.3

Figure A.10 As in Fig. A.2, except for longitudes between 129 and 140°E.

24 h — OTCM

Best Track	%0	%1	%2
L	34.2	34.2	31.6
C	34.2	65.8	
R	55.0	35.0	10.0
Total	41.4	44.8	13.8

M Score = 72.4

24 h — REC

Best Track	%0	%1	%2
L	0.0	68.4	31.6
C	50.0	50.0	
R	60.0	37.5	2.5
Total	37.1	51.7	11.2

M Score = 74.1

24 h — TOTL

Best Track	%0	%1	%2
L	13.2	68.4	18.4
C	50.0	50.0	
R	40.0	52.5	7.5
Total	34.5	56.9	8.6

M Score = 74.1

24 h — CY50

Best Track	%0	%1	%2
L	55.3	34.2	10.5
C	55.3	44.7	
R	32.5	45.0	22.5
Total	47.4	41.4	11.2

M Score = 63.8

48 h — OTCM

Best Track	%0	%1	%2
L	55.3	44.7	0.0
C	37.5	62.5	
R	42.1	55.3	2.6
Total	44.8	54.3	0.9

M Score = 56.0

48 h — REC

Best Track	%0	%1	%2
L	13.2	63.2	23.7
C	55.0	45.0	
R	65.8	31.6	2.6
Total	44.8	46.6	8.6

M Score = 63.8

48 h — TOTL

Best Track	%0	%1	%2
L	36.8	63.2	0.0
C	60.0	40.0	
R	21.1	68.4	10.5
Total	39.7	56.9	3.4

M Score = 63.8

48 h — CY50

Best Track	%0	%1	%2
L	57.9	13.2	28.9
C	47.5	52.5	
R	36.8	44.7	18.4
Total	47.4	37.1	15.5

M Score = 68.1

72 h — OTCM

Best Track	%0	%1	%2
L	57.9	42.1	0.0
C	50.0	50.0	
R	36.8	57.9	5.3
Total	48.3	50.0	1.7

M Score = 53.4

72 h — REC

Best Track	%0	%1	%2
L	21.1	63.2	15.8
C	52.5	47.5	
R	55.3	34.2	10.5
Total	43.1	48.3	8.6

M Score = 65.5

72 h — TOTL

Best Track	%0	%1	%2
L	44.7	50.0	5.3
C	62.5	37.5	
R	26.3	34.2	39.5
Total	44.8	40.5	14.7

M Score = 69.8

72 h — CY50

Best Track	%0	%1	%2
L	52.6	21.1	26.3
C	27.5	72.5	
R	39.5	42.1	18.4
Total	39.7	45.7	14.7

M Score = 75.0

Figure A.11 As in Fig. A.1, except for longitude > 140°E.

24 h — OTCM

Best Track	%0	%1	%2
S	52.6	42.1	5.3
C	41.0	59.0	
F	35.9	28.2	35.9
Total	43.1	43.1	13.8

M Score = 70.7

24 h — REC

Best Track	%0	%1	%2
S	21.1	71.1	7.9
C	51.3	48.7	
F	35.9	53.8	10.3
Total	36.2	57.8	6.0

M Score = 69.8

24 h — TOTL

Best Track	%0	%1	%2
S	10.5	73.7	15.8
C	53.8	46.2	
F	48.7	48.7	2.6
Total	37.9	56.0	6.0

M Score = 68.1

24 h — CY50

Best Track	%0	%1	%2
S	50.0	28.9	21.1
C	51.3	48.7	
F	56.4	25.6	17.9
Total	52.6	34.5	12.9

M Score = 60.3

48 h — OTCM

Best Track	%0	%1	%2
S	44.7	47.4	7.9
C	65.0	35.0	
F	42.1	50.0	7.9
Total	50.9	44.0	5.2

M Score = 54.3

48 h — REC

Best Track	%0	%1	%2
S	5.3	92.1	2.6
C	82.5	17.5	
F	57.9	42.1	0.0
Total	49.1	50.0	0.9

M Score = 51.7

48 h — TOTL

Best Track	%0	%1	%2
S	21.1	76.3	2.6
C	82.5	17.5	
F	52.6	47.4	0.0
Total	52.6	46.6	0.9

M Score = 48.3

48 h — CY50

Best Track	%0	%1	%2
S	68.4	23.7	7.9
C	35.0	65.0	
F	21.1	57.9	21.1
Total	41.4	49.1	9.5

M Score = 68.1

72 h — OTCM

Best Track	%0	%1	%2
S	39.5	42.1	18.4
C	43.6	56.4	
F	46.2	51.3	2.6
Total	43.1	50.0	6.9

M Score = 63.8

72 h — REC

Best Track	%0	%1	%2
S	28.9	57.9	13.2
C	69.2	30.8	
F	51.3	46.2	2.6
Total	50.0	44.8	5.2

M Score = 55.2

72 h — TOTL

Best Track	%0	%1	%2
S	47.4	52.6	0.0
C	66.7	33.3	
F	41.0	53.8	5.1
Total	51.7	46.6	1.7

M Score = 50.0

72 h — CY50

Best Track	%0	%1	%2
S	71.1	15.8	13.2
C	20.5	79.5	
F	12.8	56.4	30.8
Total	34.5	50.9	14.7

M Score = 80.2

Figure A.12 As in Fig. A.2, except for longitude > 140°E.

24 h — OTCM

Best Track	%0	%1	%2
L	33.3	43.6	23.1
C	30.0	70.0	
R	61.5	28.2	10.3
Total	41.5	47.5	11.0

M Score = 69.5

24 h — REC

Best Track	%0	%1	%2
L	10.3	43.6	46.2
C	22.5	77.5	
R	71.8	20.5	7.7
Total	34.7	47.5	17.8

M Score = 83.1

24 h — TOTL

Best Track	%0	%1	%2
L	28.2	41.0	30.8
C	32.5	67.5	
R	46.2	38.5	15.4
Total	35.6	49.2	15.3

M Score = 79.7

24 h — CY50

Best Track	%0	%1	%2
L	71.8	17.9	10.3
C	45.0	55.0	
R	41.0	33.3	25.6
Total	52.5	35.6	11.9

M Score = 59.3

48 h — OTCM

Best Track	%0	%1	%2
L	66.7	23.1	10.3
C	41.0	59.0	
R	45.0	35.0	20.0
Total	50.8	39.0	10.2

M Score = 59.3

48 h — REC

Best Track	%0	%1	%2
L	35.9	28.2	35.9
C	23.1	76.9	
R	67.5	25.0	7.5
Total	42.4	43.2	14.4

M Score = 72.0

48 h — TOTL

Best Track	%0	%1	%2
L	64.1	33.3	2.6
C	69.2	30.8	
R	17.5	57.5	25.0
Total	50.0	40.7	9.3

M Score = 59.3

48 h — CY50

Best Track	%0	%1	%2
L	66.7	15.4	17.9
C	43.6	56.4	
R	37.5	45.0	17.5
Total	49.2	39.0	11.9

M Score = 62.7

72 h — OTCM

Best Track	%0	%1	%2
L	61.5	35.9	2.6
C	45.0	55.0	
R	33.3	51.3	15.4
Total	46.6	47.5	5.9

M Score = 59.3

72 h — REC

Best Track	%0	%1	%2
L	23.1	51.8	25.6
C	32.5	67.6	
R	56.4	30.8	12.8
Total	37.3	50.0	12.7

M Score = 75.4

72 h — TOTL

Best Track	%0	%1	%2
L	56.4	38.5	5.1
C	65.0	35.0	
R	7.7	59.0	33.3
Total	43.2	44.1	12.7

M Score = 69.5

72 h — CY50

Best Track	%0	%1	%2
L	61.5	20.5	17.9
C	37.5	62.5	
R	30.8	51.3	17.9
Total	43.2	44.9	11.9

M Score = 68.6

Figure A.13 As in Fig. A.1, except for intensity < 55 kt.

24 h — OTCM (Best Track)

	%0	%1	%2
S	59.0	33.3	7.7
C	32.5	67.5	
F	38.5	25.6	35.9
Total	43.2	42.4	14.4

M Score = 71.2

24 h — REC (Best Track)

	%0	%1	%2
S	23.1	74.4	2.6
C	57.5	42.5	
F	33.3	51.3	15.4
Total	38.1	55.9	5.9

M Score = 67.8

24 h — TOTL (Best Track)

	%0	%1	%2
S	10.3	76.9	12.8
C	72.5	27.5	
F	43.6	51.3	5.1
Total	42.4	51.7	5.9

M Score = 63.6

24 h — CY50 (Best Track)

	%0	%1	%2
S	53.8	35.9	10.3
C	47.5	52.5	
F	64.1	23.1	12.8
Total	55.1	37.3	7.6

M Score = 52.5

48 h — OTCM (Best Track)

	%0	%1	%2
S	53.8	30.8	15.4
C	46.2	53.8	
F	47.5	22.5	30.0
Total	49.2	35.6	15.3

M Score = 66.1

48 h — REC (Best Track)

	%0	%1	%2
S	25.6	69.2	5.1
C	59.0	41.0	
F	40.0	52.5	7.5
Total	41.5	54.2	4.2

M Score = 62.7

48 h — TOTL (Best Track)

	%0	%1	%2
S	15.4	79.5	5.1
C	74.4	25.6	
F	40.0	57.5	2.5
Total	43.2	54.2	2.5

M Score = 59.3

48 h — CY50 (Best Track)

	%0	%1	%2
S	76.9	20.5	2.6
C	30.8	69.2	
F	32.5	37.5	30.0
Total	46.6	42.4	11.0

M Score = 64.4

72 h — OTCM (Best Track)

	%0	%1	%2
S	30.8	41.0	28.2
C	20.0	80.0	
F	53.8	38.5	7.7
Total	34.7	53.4	11.9

M Score = 77.1

72 h — REC (Best Track)

	%0	%1	%2
S	33.3	59.0	7.7
C	40.0	60.0	
F	38.5	51.3	10.3
Total	37.3	56.8	5.9

M Score = 68.6

72 h — TOTL (Best Track)

	%0	%1	%2
S	23.1	56.4	20.5
C	52.5	47.5	
F	48.7	51.3	0.0
Total	41.5	51.7	6.8

M Score = 65.3

72 h — CY50 (Best Track)

	%0	%1	%2
S	79.5	10.3	10.3
C	15.0	85.0	
F	35.9	20.5	43.6
Total	43.2	39.0	17.8

M Score = 74.6

Figure A.14 As in Fig. A.2, except for intensity < 55 kt.

24 h — OTCM

Best Track	%0	%1	%2
L	35.3	41.2	23.5
C	32.4	67.6	
R	69.7	24.2	6.1
Total	45.2	45.2	9.6

M Score = 64.4

24 h — REC

Best Track	%0	%1	%2
L	14.7	64.7	20.6
C	43.2	56.8	
R	69.7	30.3	0.0
Total	42.3	51.0	6.7

M Score = 64.4

24 h — TOTL

Best Track	%0	%1	%2
L	29.4	64.7	5.9
C	70.3	29.7	
R	18.2	72.7	9.1
Total	40.4	54.8	4.8

M Score = 64.4

24 h — CY50

Best Track	%0	%1	%2
L	61.8	35.3	2.9
C	43.2	56.8	
R	24.2	54.5	21.2
Total	43.3	49.0	7.7

M Score = 64.4

48 h — OTCM

Best Track	%0	%1	%2
L	61.8	26.5	11.8
C	44.4	55.6	
R	44.1	52.9	2.9
Total	50.0	45.2	4.8

M Score = 54.8

48 h — REC

Best Track	%0	%1	%2
L	14.7	50.0	35.3
C	50.0	50.0	
R	50.0	47.1	2.9
Total	38.5	49.0	12.5

M Score = 74.0

48 h — TOTL

Best Track	%0	%1	%2
L	44.1	50.0	5.9
C	80.6	19.4	
R	0.0	79.4	20.6
Total	42.3	49.0	8.7

M Score = 66.3

48 h — CY50

Best Track	%0	%1	%2
L	47.1	35.3	17.6
C	47.2	52.8	
R	32.4	64.7	2.9
Total	42.3	51.0	6.7

M Score = 64.4

72 h — OTCM

Best Track	%0	%1	%2
L	52.9	38.2	8.8
C	42.9	57.1	
R	31.4	62.9	5.7
Total	42.3	52.9	4.8

M Score = 62.5

72 h — REC

Best Track	%0	%1	%2
L	11.8	47.1	41.2
C	57.1	42.9	
R	65.7	28.6	5.7
Total	45.2	39.4	15.4

M Score = 70.2

72 h — TOTL

Best Track	%0	%1	%2
L	41.2	50.0	8.8
C	74.3	25.7	
R	2.9	77.1	20.0
Total	39.4	51.0	9.6

M Score = 70.2

72 h — CY50

Best Track	%0	%1	%2
L	35.3	32.4	32.4
C	51.4	48.6	
R	40.0	51.4	8.6
Total	42.3	44.2	13.5

M Score = 71.2

Figure A.15 As in Fig. A.1, except for intensity between 55 and 90 kt.

24 h — OTCM

Best Track	%0	%1	%2
S	56.3	43.8	0.0
C	50.0	50.0	
F	44.1	26.5	29.4
Total	50.0	40.4	9.6

M Score = 59.6

24 h — REC

Best Track	%0	%1	%2
S	31.3	65.6	3.1
C	71.1	28.9	
F	23.5	61.8	14.7
Total	43.3	51.0	5.8

M Score = 62.5

24 h — TOTL

Best Track	%0	%1	%2
S	9.4	84.4	6.3
C	71.1	28.9	
F	47.1	50.0	2.9
Total	44.2	52.9	2.9

M Score = 58.7

24 h — CY50

Best Track	%0	%1	%2
S	53.1	37.5	9.4
C	47.4	52.6	
F	35.3	32.4	32.4
Total	45.2	41.3	13.5

M Score = 68.3

48 h — OTCM

Best Track	%0	%1	%2
S	44.1	50.0	5.9
C	52.8	47.2	
F	50.0	29.4	20.6
Total	49.0	42.3	8.7

M Score = 59.6

48 h — REC

Best Track	%0	%1	%2
S	23.5	73.5	2.9
C	75.0	25.0	
F	52.9	35.3	11.8
Total	51.0	44.2	4.8

M Score = 53.8

48 h — TOTL

Best Track	%0	%1	%2
S	17.6	73.5	8.8
C	75.0	25.0	
F	52.9	47.1	0.0
Total	49.0	48.1	2.9

M Score = 53.8

48 h — CY50

Best Track	%0	%1	%2
S	73.5	20.6	5.9
C	25.0	75.0	
F	26.5	35.3	38.2
Total	41.3	44.2	14.4

M Score = 73.1

72 h — OTCM

Best Track	%0	%1	%2
S	47.1	41.2	11.8
C	44.4	55.6	
F	44.1	38.2	17.6
Total	45.2	45.2	9.6

M Score = 64.4

72 h — REC

Best Track	%0	%1	%2
S	44.1	38.2	17.6
C	36.1	63.9	
F	58.8	29.4	11.8
Total	46.2	44.2	9.6

M Score = 63.5

72 h — TOTL

Best Track	%0	%1	%2
S	29.4	64.7	5.9
C	61.1	38.9	
F	64.7	29.4	5.9
Total	51.9	44.2	3.8

M Score = 51.9

72 h — CY50

Best Track	%0	%1	%2
S	88.2	2.9	8.8
C	16.7	83.3	
F	14.7	17.6	67.6
Total	39.4	35.6	25.0

M Score = 85.6

Figure A.16 As in Fig. A.2, except for intensity between 55 and 90 kt.

OTCM

24 h

Best Track	%0	%1	%2
L	34.1	34.1	31.8
C	28.3	71.7	
R	63.6	22.7	13.6
Total	41.8	43.3	14.9

M Score = 73.1

48 h

Best Track	%0	%1	%2
L	63.6	25.0	11.4
C	37.0	63.0	
R	50.0	25.0	25.0
Total	50.0	38.1	11.9

M Score = 61.9

72 h

Best Track	%0	%1	%2
L	65.9	22.7	11.4
C	30.4	69.6	
R	43.2	15.9	40.9
Total	46.3	36.6	17.2

M Score = 70.9

REC

24 h

Best Track	%0	%1	%2
L	15.9	54.5	29.5
C	56.5	43.5	
R	29.5	65.9	4.5
Total	34.3	54.5	11.2

M Score = 76.9

48 h

Best Track	%0	%1	%2
L	25.0	40.9	34.1
C	47.8	52.2	
R	25.0	65.9	9.1
Total	32.8	53.0	14.2

M Score = 81.3

72 h

Best Track	%0	%1	%2
L	34.1	31.8	34.1
C	47.8	52.2	
R	31.3	54.5	13.6
Total	38.1	46.3	15.7

M Score = 77.6

TOTL

24 h

Best Track	%0	%1	%2
L	47.7	43.2	9.1
C	34.8	65.2	
R	9.1	40.9	50.0
Total	30.6	50.0	19.4

M Score = 88.8

48 h

Best Track	%0	%1	%2
L	84.1	15.9	0.0
C	26.1	73.9	
R	2.3	22.7	75.0
Total	37.3	38.1	24.6

M Score = 87.3

72 h

Best Track	%0	%1	%2
L	90.9	9.1	0.0
C	10.9	89.1	
R	0.0	6.8	93.2
Total	33.6	35.8	30.6

M Score = 97.0

CY50

24 h

Best Track	%0	%1	%2
L	47.7	38.6	13.6
C	58.7	41.3	
R	38.6	47.7	13.6
Total	48.5	42.5	9.0

M Score = 60.4

48 h

Best Track	%0	%1	%2
L	29.5	25.0	45.5
C	39.1	60.9	
R	52.3	38.6	9.1
Total	40.3	41.8	17.9

M Score = 77.6

72 h

Best Track	%0	%1	%2
L	27.3	22.7	50.0
C	41.3	58.7	
R	50.0	43.2	6.8
Total	39.6	41.8	18.7

M Score = 79.1

Figure A.17 As in Fig. A.1, except for intensity > 90 kt.

24 h OTCM

Best Track	%0	%1	%2
S	61.4	27.3	11.4
C	22.2	77.8	
F	57.8	24.4	17.8
Total	47.0	43.3	9.7

M Score = 62.7

24 h REC

Best Track	%0	%1	%2
S	15.9	61.4	22.7
C	57.8	42.2	
F	53.3	40.0	6.7
Total	42.5	47.8	9.7

M Score = 67.2

24 h TOTL

Best Track	%0	%1	%2
S	20.5	38.6	40.9
C	28.9	71.1	
F	73.3	26.7	0.0
Total	41.0	45.5	13.4

M Score = 72.4

24 h CY50

Best Track	%0	%1	%2
S	63.6	20.5	15.9
C	26.7	73.3	
F	53.3	26.7	20.0
Total	47.8	40.3	11.9

M Score = 64.2

48 h OTCM

Best Track	%0	%1	%2
S	38.6	36.4	25.0
C	45.7	54.3	
F	79.5	13.6	6.8
Total	54.5	35.1	10.4

M Score = 56.0

48 h REC

Best Track	%0	%1	%2
S	9.1	34.1	56.8
C	34.8	65.2	
F	63.6	34.1	2.3
Total	35.8	44.8	19.4

M Score = 83.6

48 h TOTL

Best Track	%0	%1	%2
S	22.7	40.9	36.4
C	32.6	67.4	
F	75.0	22.7	2.3
Total	43.3	44.0	12.7

M Score = 69.4

48 h CY50

Best Track	%0	%1	%2
S	77.3	4.5	18.2
C	17.4	82.6	
F	31.8	31.8	36.4
Total	41.8	40.3	17.9

M Score = 76.1

72 h OTCM

Best Track	%0	%1	%2
S	42.9	26.2	31.0
C	41.7	58.3	
F	70.5	27.3	2.3
Total	51.5	38.1	10.4

M Score = 59.0

72 h REC

Best Track	%0	%1	%2
S	14.3	31.0	54.8
C	35.4	64.6	
F	59.1	36.4	4.5
Total	36.6	44.8	18.7

M Score = 82.1

72 h TOTL

Best Track	%0	%1	%2
S	45.2	40.5	14.3
C	29.2	70.8	
F	20.5	63.6	15.9
Total	31.3	59.0	9.7

M Score = 78.4

72 h CY50

Best Track	%0	%1	%2
S	78.6	0.0	21.4
C	12.5	87.5	
F	20.5	34.1	45.5
Total	35.8	42.5	21.6

M Score = 85.8

Figure A.18 As in Fig. A.2, except for intensity > 90 kt.

OTCM — 24 h

Best Track	%0	%1	%2
L	52.2	30.4	17.4
C	41.7	58.3	
R	58.3	29.2	12.5
Total	50.7	39.4	9.9

M Score = 59.2

REC — 24 h

Best Track	%0	%1	%2
L	17.4	47.8	34.8
C	58.3	41.7	
R	33.3	58.3	8.3
Total	36.6	49.3	14.1

M Score = 77.5

TOTL — 24 h

Best Track	%0	%1	%2
L	43.5	52.2	4.3
C	33.3	66.7	
R	0.0	41.7	58.3
Total	25.4	53.5	21.1

M Score = 95.8

CY50 — 24 h

Best Track	%0	%1	%2
L	56.5	30.4	13.0
C	41.7	58.3	
R	50.0	45.8	4.2
Total	49.3	45.1	5.6

M Score = 56.3

OTCM — 48 h

Best Track	%0	%1	%2
L	52.2	39.1	8.7
C	33.3	66.7	
R	29.2	54.2	16.7
Total	38.0	53.5	8.5

M Score = 70.4

REC — 48 h

Best Track	%0	%1	%2
L	26.1	39.1	34.8
C	54.2	45.8	
R	25.0	75.0	0.0
Total	35.2	53.5	11.3

M Score = 76.1

TOTL — 48 h

Best Track	%0	%1	%2
L	56.5	39.1	4.3
C	41.7	58.3	
R	0.0	29.2	70.8
Total	32.4	42.3	25.4

M Score = 93.0

CY50 — 48 h

Best Track	%0	%1	%2
L	30.4	39.1	30.4
C	62.5	37.5	
R	54.2	41.7	4.2
Total	49.3	39.4	11.3

M Score = 62.0

OTCM — 72 h

Best Track	%0	%1	%2
L	65.2	21.7	13.0
C	32.0	68.0	
R	17.4	52.2	30.4
Total	38.0	47.9	14.1

M Score = 76.1

REC — 72 h

Best Track	%0	%1	%2
L	30.4	39.1	30.4
C	60.0	40.0	
R	30.4	65.2	4.3
Total	40.8	47.9	11.3

M Score = 70.4

TOTL — 72 h

Best Track	%0	%1	%2
L	69.6	26.1	4.3
C	40.0	60.0	
R	0.0	21.7	78.3
Total	36.6	36.6	26.8

M Score = 90.1

CY50 — 72 h

Best Track	%0	%1	%2
L	34.8	17.4	47.8
C	56.0	44.0	
R	65.2	30.4	4.3
Total	52.1	31.0	16.9

M Score = 64.8

Figure A.19 As in Fig. A.1, except for 12-h intensity change < 0 kt.

24 h — OTCM

Best Track	%0	%1	%2
S	59.1	36.4	4.5
C	34.6	65.4	
F	34.8	21.7	43.5
Total	42.3	42.3	15.5

M Score = 73.2

24 h — REC

Best Track	%0	%1	%2
S	27.3	68.2	4.5
C	53.8	46.2	
F	47.8	26.1	26.1
Total	43.7	46.5	9.9

M Score = 66.2

24 h — TOTL

Best Track	%0	%1	%2
S	22.7	59.1	18.2
C	46.2	53.8	
F	65.2	21.7	13.0
Total	45.1	45.1	9.9

M Score = 64.8

24 h — CY50

Best Track	%0	%1	%2
S	72.7	13.6	13.6
C	46.2	53.8	
F	47.8	21.7	30.4
Total	54.9	31.0	14.1

M Score = 59.2

48 h — OTCM

Best Track	%0	%1	%2
S	73.9	17.4	8.7
C	45.8	54.2	
F	45.8	29.2	25.0
Total	54.9	33.8	11.3

M Score = 56.3

48 h — REC

Best Track	%0	%1	%2
S	26.1	56.5	17.4
C	58.3	41.7	
F	33.3	37.5	29.2
Total	39.4	45.1	15.5

M Score = 76.1

48 h — TOTL

Best Track	%0	%1	%2
S	39.1	39.1	21.7
C	50.0	50.0	
F	33.3	54.2	12.5
Total	40.8	47.9	11.3

M Score = 70.4

48 h — CY50

Best Track	%0	%1	%2
S	78.3	8.7	13.0
C	37.5	62.5	
F	12.5	25.0	62.5
Total	42.3	32.4	25.4

M Score = 83.1

72 h — OTCM

Best Track	%0	%1	%2
S	56.5	30.4	13.0
C	20.0	80.0	
F	47.8	39.1	13.0
Total	40.8	50.7	8.5

M Score = 67.6

72 h — REC

Best Track	%0	%1	%2
S	26.1	43.5	30.4
C	68.0	32.0	
F	34.8	47.8	17.4
Total	43.7	40.8	15.5

M Score = 71.8

72 h — TOTL

Best Track	%0	%1	%2
S	73.9	26.1	0.0
C	44.0	56.0	
F	17.4	60.9	21.7
Total	45.1	47.9	7.0

M Score = 62.0

72 h — CY50

Best Track	%0	%1	%2
S	69.6	8.7	21.7
C	16.0	84.0	
F	13.0	30.4	56.5
Total	32.4	42.3	25.4

M Score = 93.0

Figure A.20 As in Fig. A.2, except for 12-h intensity change < 0 kt.

24 h — OTCM

Best Track	%0	%1	%2
L	38.8	32.7	28.6
C	21.6	78.4	
R	65.3	26.5	8.2
Total	41.6	46.3	21.1

M Score = 70.5

24 h — REC

Best Track	%0	%1	%2
L	14.3	46.9	38.8
C	33.3	66.7	
R	67.3	30.6	2.0
Total	38.3	48.3	13.4

M Score = 75.2

24 h — TOTL

Best Track	%0	%1	%2
L	42.9	34.7	22.4
C	62.7	37.3	
R	34.7	49.0	16.3
Total	47.0	40.3	12.8

M Score = 65.8

24 h — CY50

Best Track	%0	%1	%2
L	60.0	33.3	6.7
C	52.2	47.8	
R	15.6	64.4	20.0
Total	42.6	48.5	8.8

M Score = 66.2

48 h — OTCM

Best Track	%0	%1	%2
L	65.3	20.4	14.3
C	44.0	56.0	
R	46.0	38.0	16.0
Total	51.7	38.3	10.1

M Score = 58.4

48 h — REC

Best Track	%0	%1	%2
L	26.5	40.8	32.7
C	50.0	50.0	
R	60.0	38.0	2.0
Total	45.6	43.0	11.4

M Score = 65.8

48 h — TOTL

Best Track	%0	%1	%2
L	69.4	26.5	4.1
C	56.0	44.0	
R	6.0	72.0	22.0
Total	43.6	47.7	8.7

M Score = 65.1

48 h — CY50

Best Track	%0	%1	%2
L	42.2	22.2	35.6
C	28.3	71.7	
R	31.1	53.3	15.6
Total	33.8	49.3	16.9

M Score = 83.1

72 h — OTCM

Best Track	%0	%1	%2
L	61.2	32.7	6.1
C	44.0	56.0	
R	46.0	38.0	16.0
Total	50.3	42.3	7.4

M Score = 57.0

72 h — REC

Best Track	%0	%1	%2
L	20.4	42.9	36.7
C	44.0	56.0	
R	62.0	30.0	8.0
Total	42.3	43.0	14.8

M Score = 72.5

72 h — TOTL

Best Track	%0	%1	%2
L	67.3	26.5	6.1
C	42.0	58.0	
R	6.0	50.0	44.0
Total	38.3	45.0	16.8

M Score = 78.5

72 h — CY50

Best Track	%0	%1	%2
L	35.6	37.8	26.7
C	37.0	63.0	
R	31.1	48.9	20.0
Total	34.6	50.0	15.4

M Score = 80.9

Figure A.21 As in Fig. A.1, except for 12-h intensity change 0 to 5 kt.

OTCM — 24 h

Best Track	%0	%1	%2
S	62.5	33.3	4.2
C	46.2	53.8	
F	40.8	30.6	28.6
Total	49.7	39.6	10.7

M Score = 61.1

OTCM — 48 h

Best Track	%0	%1	%2
S	44.9	38.8	16.3
C	43.1	56.9	
F	57.1	30.6	12.2
Total	48.3	42.3	9.4

M Score = 61.1

OTCM — 72 h

Best Track	%0	%1	%2
S	32.7	40.8	26.5
C	30.0	70.0	
F	48.0	36.0	16.0
Total	36.9	49.0	14.1

M Score = 77.2

REC — 24 h

Best Track	%0	%1	%2
S	29.2	66.7	4.2
C	69.2	30.8	
F	36.7	53.1	10.2
Total	45.6	49.7	4.7

M Score = 59.1

REC — 48 h

Best Track	%0	%1	%2
S	26.5	67.3	6.1
C	52.9	47.1	
F	53.1	42.9	4.1
Total	44.3	52.3	3.4

M Score = 59.1

REC — 72 h

Best Track	%0	%1	%2
S	38.8	38.8	22.4
C	30.0	70.0	
F	50.0	38.0	12.0
Total	39.6	49.0	11.4

M Score = 71.8

TOTL — 24 h

Best Track	%0	%1	%2
S	12.5	75.0	12.5
C	61.5	38.5	
F	46.9	49.1	4.1
Total	40.9	53.7	5.4

M Score = 64.4

TOTL — 48 h

Best Track	%0	%1	%2
S	18.4	61.2	20.4
C	51.0	49.0	
F	71.4	26.5	2.0
Total	47.0	45.6	7.4

M Score = 60.4

TOTL — 72 h

Best Track	%0	%1	%2
S	36.7	40.8	22.4
C	52.0	48.0	
F	44.0	48.0	8.0
Total	44.3	45.6	10.1

M Score = 65.8

CY50 — 24 h

Best Track	%0	%1	%2
S	54.2	33.3	12.5
C	51.9	48.1	
F	49.0	28.6	22.4
Total	51.7	36.9	11.4

M Score = 59.7

CY50 — 48 h

Best Track	%0	%1	%2
S	79.6	12.2	8.2
C	33.3	66.7	
F	34.7	30.6	34.7
Total	49.0	36.9	14.1

M Score = 65.1

CY50 — 72 h

Best Track	%0	%1	%2
S	89.8	2.0	8.2
C	14.0	86.0	
F	26.0	24.0	50.0
Total	43.0	37.6	19.5

M Score = 76.5

Figure A.22 As in Fig. A.2, except for 12-h intensity change 0 to 5 kt.

24 h — OTCM

Best Track	%0	%1	%2
L	26.7	46.7	26.7
C	28.3	71.7	
R	75.6	15.6	8.9
Total	43.4	44.9	11.8

M Score = 68.4

24 h — REC

Best Track	%0	%1	%2
L	15.6	51.1	33.3
C	41.3	58.7	
R	57.8	40.0	2.2
Total	38.2	50.0	11.8

M Score = 73.5

24 h — TOTL

Best Track	%0	%1	%2
L	31.1	60.0	8.9
C	39.1	60.9	
R	24.4	60.0	15.6
Total	31.6	60.3	8.1

M Score = 76.5

24 h — CY50

Best Track	%0	%1	%2
L	60.0	33.3	6.7
C	52.2	47.8	
R	15.6	64.4	20.0
Total	42.6	48.5	8.8

M Score = 66.2

48 h — OTCM

Best Track	%0	%1	%2
L	62.2	22.2	15.6
C	34.8	65.2	
R	48.9	37.8	13.3
Total	48.5	41.9	9.6

M Score = 61.0

48 h — REC

Best Track	%0	%1	%2
L	24.4	44.4	31.1
C	32.6	67.4	
R	60.0	33.3	6.7
Total	39.0	48.5	12.5

M Score = 73.5

48 h — TOTL

Best Track	%0	%1	%2
L	73.3	26.7	0.0
C	47.8	52.2	
R	6.7	46.7	46.7
Total	42.6	41.9	15.4

M Score = 72.8

48 h — CY50

Best Track	%0	%1	%2
L	42.2	22.2	35.6
C	28.3	71.7	
R	31.1	53.3	15.6
Total	33.8	49.3	16.9

M Score = 83.1

72 h — OTCM

Best Track	%0	%1	%2
L	62.2	26.7	11.1
C	45.7	54.3	
R	33.3	51.1	15.6
Total	47.1	44.1	8.8

M Score = 61.8

72 h — REC

Best Track	%0	%1	%2
L	24.4	37.8	37.8
C	47.8	52.2	
R	57.8	31.1	11.1
Total	43.4	40.4	16.2

M Score = 72.8

72 h — TOTL

Best Track	%0	%1	%2
L	68.9	26.7	4.4
C	50.0	50.0	
R	6.7	53.3	40.0
Total	41.9	43.4	14.7

M Score = 72.8

72 h — CY50

Best Track	%0	%1	%2
L	35.6	37.8	26.7
C	37.0	63.0	
R	31.1	48.9	20.0
Total	34.6	50.0	15.4

M Score = 80.9

Figure A.23 As in Fig. A.1, except for 12-h intensity change > 5 kt.

OTCM

24 h

Best Track	%0	%1	%2
S	54.5	43.2	2.3
C	40.4	59.6	
F	37.8	33.3	28.9
Total	44.1	45.6	10.3

M Score = 66.2

48 h

Best Track	%0	%1	%2
S	40.0	46.7	13.3
C	51.1	48.9	
F	54.3	34.8	10.9
Total	48.5	43.4	8.1

M Score = 59.6

72 h

Best Track	%0	%1	%2
S	33.3	35.6	31.1
C	41.3	58.7	
F	71.1	20.0	8.9
Total	48.5	38.2	13.2

M Score = 64.7

REC

24 h

Best Track	%0	%1	%2
S	13.6	75.0	11.4
C	55.3	44.7	
F	40.0	51.1	8.9
Total	36.8	56.6	6.6

M Score = 69.9

48 h

Best Track	%0	%1	%2
S	8.9	57.8	33.3
C	51.1	48.9	
F	63.0	37.0	0.0
Total	41.2	47.8	11.0

M Score = 69.9

72 h

Best Track	%0	%1	%2
S	20.0	46.7	33.3
C	30.4	69.6	
F	73.3	22.2	4.4
Total	41.2	46.3	12.5

M Score = 71.3

TOTL

24 h

Best Track	%0	%1	%2
S	11.4	70.5	18.2
C	48.9	51.1	
F	64.4	35.6	0.0
Total	41.9	52.2	5.9

M Score = 64.0

48 h

Best Track	%0	%1	%2
S	17.8	48.9	33.3
C	40.0	60.0	
F	73.9	26.1	0.0
Total	44.1	44.9	11.0

M Score = 66.9

72 h

Best Track	%0	%1	%2
S	24.4	51.1	24.4
C	37.0	63.0	
F	64.4	31.1	4.4
Total	41.9	48.5	9.6

M Score = 67.6

CY50

24 h

Best Track	%0	%1	%2
S	54.5	34.1	11.4
C	44.7	55.3	
F	53.3	28.9	17.8
Total	50.7	39.7	9.6

M Score = 58.8

48 h

Best Track	%0	%1	%2
S	75.6	15.6	8.9
C	24.4	75.6	
F	26.1	37.0	37.0
Total	41.9	42.6	15.4

M Score = 73.5

72 h

Best Track	%0	%1	%2
S	80.0	4.4	15.6
C	17.4	82.6	
F	22.2	26.7	51.1
Total	39.7	38.2	22.1

M Score = 82.4

Figure A.24 As in Fig. A.2, except for 12-h intensity change > 5 kt.

24 h OTCM

Best Track	%0	%1	%2
L	31.6	42.1	26.3
C	22.5	77.5	
R	73.7	18.4	7.9
Total	42.2	46.6	11.2

M Score = 69.0

24 h REC

Best Track	%0	%1	%2
L	13.2	42.1	44.7
C	20.0	80.0	
R	60.5	31.6	7.9
Total	31.0	51.7	17.2

M Score = 86.2

24 h TOTL

Best Track	%0	%1	%2
L	31.6	42.1	26.3
C	42.5	57.5	
R	31.6	44.7	23.7
Total	35.3	48.3	16.4

M Score = 81.0

24 h CY50

Best Track	%0	%1	%2
L	71.1	18.4	10.5
C	52.5	47.5	
R	36.8	34.2	28.9
Total	53.4	33.6	12.9

M Score = 59.5

48 h OTCM

Best Track	%0	%1	%2
L	65.8	23.7	10.5
C	37.5	62.6	
R	55.3	28.9	15.8
Total	52.6	38.8	8.6

M Score = 56.0

48 h REC

Best Track	%0	%1	%2
L	36.8	15.8	47.4
C	20.0	80.0	
R	68.4	26.3	5.3
Total	41.4	41.4	17.2

M Score = 75.9

48 h TOTL

Best Track	%0	%1	%2
L	68.4	28.9	2.6
C	55.0	45.0	
R	15.8	47.4	36.8
Total	46.6	40.5	12.9

M Score = 66.4

48 h CY50

Best Track	%0	%1	%2
L	76.3	7.9	15.8
C	42.5	57.5	
R	34.2	52.6	13.2
Total	50.9	39.7	9.5

M Score = 58.6

72 h OTCM

Best Track	%0	%1	%2
L	57.9	36.8	5.3
C	35.9	64.1	
R	46.2	46.2	7.7
Total	46.6	49.1	4.3

M Score = 67.8

72 h REC

Best Track	%0	%1	%2
L	13.2	55.3	31.6
C	30.8	69.2	
R	61.5	23.1	15.4
Total	35.3	49.1	15.5

M Score = 80.2

72 h TOTL

Best Track	%0	%1	%2
L	47.7	44.7	7.9
C	61.5	38.5	
R	12.8	66.7	20.5
Total	40.5	50.0	9.5

M Score = 69.0

72 h CY50

Best Track	%0	%1	%2
L	60.5	28.9	10.5
C	38.5	61.5	
R	33.3	53.8	12.8
Total	44.0	48.3	7.8

M Score = 63.8

Figure A.25 As in Fig. A.1, except for size < 135 n mi.

24 h OTCM

Best Track	%0	%1	%2
S	60.5	34.2	5.3
C	41.0	59.0	
F	51.3	12.8	35.9
Total	50.9	35.3	13.8

M Score = 62.9

24 h REC

Best Track	%0	%1	%2
S	31.6	63.2	5.3
C	66.7	33.3	
F	35.9	51.3	12.8
Total	44.8	49.1	6.0

M Score = 61.2

24 h TOTL

Best Track	%0	%1	%2
S	5.3	84.2	10.5
C	69.2	30.8	
F	48.7	46.2	5.1
Total	41.4	53.4	5.2

M Score = 63.8

24 h CY50

Best Track	%0	%1	%2
S	44.7	42.1	13.2
C	48.7	51.3	
F	66.7	23.1	10.3
Total	53.4	38.8	7.8

M Score = 54.3

48 h OTCM

Best Track	%0	%1	%2
S	60.5	26.3	13.2
C	43.6	56.4	
F	56.4	15.4	28.2
Total	53.4	32.8	13.8

M Score = 60.3

48 h REC

Best Track	%0	%1	%2
S	34.2	63.2	2.6
C	48.7	51.3	
F	53.8	35.9	10.3
Total	45.7	50.0	4.3

M Score = 58.6

48 h TOTL

Best Track	%0	%1	%2
S	13.2	65.8	21.1
C	53.8	46.2	
F	56.4	35.9	7.7
Total	41.4	49.1	9.5

M Score = 68.1

48 h CY50

Best Track	%0	%1	%2
S	81.6	18.4	0.0
C	33.3	66.7	
F	41.0	23.1	35.9
Total	51.7	36.2	12.1

M Score = 60.3

72 h OTCM

Best Track	%0	%1	%2
S	34.2	36.8	28.9
C	22.5	77.5	
F	52.6	36.8	10.5
Total	36.2	50.9	12.9

M Score = 76.7

72 h REC

Best Track	%0	%1	%2
S	39.5	52.6	7.9
C	37.5	62.5	
F	36.8	52.6	10.5
Total	37.9	56.0	6.0

M Score = 68.1

72 h TOTL

Best Track	%0	%1	%2
S	23.7	57.9	18.4
C	65.0	35.0	
F	52.6	47.4	0.0
Total	47.4	46.6	6.0

M Score = 58.6

72 h CY50

Best Track	%0	%1	%2
S	78.9	10.5	10.5
C	12.5	87.5	
F	34.2	28.9	36.8
Total	41.4	43.1	15.5

M Score = 74.1

Figure A.26 As in Fig. A.2, except for size < 135 n mi.

OTCM — 24 h

Best Track	%0	%1	%2
L	36.8	36.8	26.3
C	28.2	71.8	
R	71.1	23.7	5.3
Total	45.2	44.3	10.4

M Score = 65.2

REC — 24 h

Best Track	%0	%1	%2
L	18.4	55.3	26.3
C	28.2	71.8	
R	78.9	21.1	0.0
Total	41.7	49.6	8.7

M Score = 67.0

TOTL — 24 h

Best Track	%0	%1	%2
L	47.4	36.8	15.8
C	53.8	46.2	
R	50.0	42.1	7.9
Total	50.4	41.7	7.8

M Score = 57.4

CY50 — 24 h

Best Track	%0	%1	%2
L	63.2	26.3	10.5
C	41.0	59.0	
R	36.8	42.1	21.1
Total	47.0	42.6	10.4

M Score = 63.5

OTCM — 48 h

Best Track	%0	%1	%2
L	60.5	23.7	15.8
C	38.5	61.5	
R	36.8	57.9	5.3
Total	45.2	47.8	7.0

M Score = 61.7

REC — 48 h

Best Track	%0	%1	%2
L	31.6	36.8	31.6
C	51.3	48.7	
R	68.4	31.6	0.0
Total	50.4	39.1	10.4

M Score = 60.0

TOTL — 48 h

Best Track	%0	%1	%2
L	60.5	34.2	5.3
C	64.1	35.9	
R	5.3	86.8	7.9
Total	43.5	52.2	4.3

M Score = 60.9

CY50 — 48 h

Best Track	%0	%1	%2
L	36.8	36.8	26.3
C	53.8	46.2	
R	31.6	60.5	7.9
Total	40.9	47.8	11.3

M Score = 70.4

OTCM — 72 h

Best Track	%0	%1	%2
L	63.2	26.3	10.5
C	36.8	63.2	
R	23.1	66.7	10.3
Total	40.9	52.2	7.0

M Score = 66.1

REC — 72 h

Best Track	%0	%1	%2
L	34.2	36.8	28.9
C	50.0	50.0	
R	66.7	33.3	0.0
Total	50.4	40.0	9.6

M Score = 59.1

TOTL — 72 h

Best Track	%0	%1	%2
L	76.3	21.1	2.6
C	47.4	52.6	
R	0.0	71.8	28.2
Total	40.9	48.7	10.4

M Score = 69.6

CY50 — 72 h

Best Track	%0	%1	%2
L	31.6	26.3	42.1
C	52.6	47.4	
R	35.9	46.2	17.9
Total	40.0	40.0	20.0

M Score = 80.0

Figure A.27 As in Fig. A.1, except for size between 135 and 220 n mi.

24 h OTCM

Best Track	%0	%1	%2
S	60.5	36.8	2.6
C	33.3	66.7	
F	39.5	34.2	26.3
Total	44.3	46.1	9.6

M Score = 65.2

24 h REC

Best Track	%0	%1	%2
S	18.4	73.7	7.9
C	56.4	43.6	
F	34.2	50.0	15.8
Total	36.5	55.7	7.8

M Score = 71.3

24 h TOTL

Best Track	%0	%1	%2
S	7.9	76.3	15.8
C	56.4	43.6	
F	47.4	47.4	5.3
Total	37.4	55.7	7.0

M Score = 69.6

24 h CY50

Best Track	%0	%1	%2
S	76.3	21.1	2.6
C	56.4	43.6	
F	52.6	26.3	21.1
Total	61.7	30.4	7.8

M Score = 46.1

48 h OTCM

Best Track	%0	%1	%2
S	42.1	42.1	15.8
C	46.2	53.8	
F	60.5	23.7	15.8
Total	49.6	40.0	10.4

M Score = 60.9

48 h REC

Best Track	%0	%1	%2
S	7.9	57.9	34.2
C	56.4	43.6	
F	47.4	42.1	10.5
Total	37.4	47.8	14.8

M Score = 77.4

48 h TOTL

Best Track	%0	%1	%2
S	23.7	55.3	21.1
C	48.7	51.3	
F	55.3	44.7	0.0
Total	42.6	50.4	7.0

M Score = 64.3

48 h CY50

Best Track	%0	%1	%2
S	86.8	13.2	0.0
C	23.1	76.9	
F	26.3	31.6	42.1
Total	45.2	40.9	13.9

M Score = 68.7

72 h OTCM

Best Track	%0	%1	%2
S	34.2	36.8	28.9
C	18.4	81.6	
F	71.8	25.6	2.6
Total	41.7	47.8	10.4

M Score = 68.7

72 h REC

Best Track	%0	%1	%2
S	21.1	36.8	42.1
C	34.2	65.8	
F	66.7	23.1	10.3
Total	40.9	41.7	17.4

M Score = 76.5

72 h TOTL

Best Track	%0	%1	%2
S	36.8	47.4	15.8
C	55.3	44.7	
F	61.5	35.9	2.6
Total	51.3	42.6	6.1

M Score = 54.8

72 h CY50

Best Track	%0	%1	%2
S	92.1	5.3	2.6
C	21.1	78.9	
F	15.4	35.9	48.7
Total	42.6	40.0	17.4

M Score = 74.8

Figure A.28 As in Fig. A.2, except for size between 135 and 200 n mi.

24 h OTCM

Best Track	%0	%1	%2
L	34.1	39.0	26.8
C	39.5	60.5	
R	53.7	31.7	14.6
Total	42.4	44.0	13.6

M Score = 71.2

24 h REC

Best Track	%0	%1	%2
L	12.2	70.7	17.1
C	74.4	25.6	
R	22.0	75.6	2.4
Total	36.8	56.8	6.4

M Score = 69.6

24 h TOTL

Best Track	%0	%1	%2
L	34.1	65.9	0.0
C	55.8	44.2	
R	2.4	58.5	39.0
Total	31.2	56.0	12.8

M Score = 81.6

24 h CY50

Best Track	%0	%1	%2
L	53.7	39.0	7.3
C	58.1	41.9	
R	34.1	51.2	14.6
Total	48.8	44.0	7.2

M Score = 58.4

48 h OTCM

Best Track	%0	%1	%2
L	63.4	29.3	7.3
C	52.4	47.6	
R	40.5	35.7	23.8
Total	52.0	37.6	10.4

M Score = 58.4

48 h REC

Best Track	%0	%1	%2
L	12.2	63.4	24.4
C	69.0	31.0	
R	19.0	76.2	4.8
Total	33.6	56.8	9.6

M Score = 76.0

48 h TOTL

Best Track	%0	%1	%2
L	68.3	29.3	2.4
C	31.0	69.0	
R	2.4	31.0	66.7
Total	33.6	43.2	23.2

M Score = 89.6

48 h CY50

Best Track	%0	%1	%2
L	34.1	31.7	34.1
C	40.5	59.5	
R	47.6	42.9	9.5
Total	40.8	44.8	14.4

M Score = 73.6

72 h OTCM

Best Track	%0	%1	%2
L	78.0	17.1	4.9
C	44.2	55.8	
R	34.1	24.4	41.5
Total	52.0	32.8	15.2

M Score = 63.2

72 h REC

Best Track	%0	%1	%2
L	19.5	48.8	31.7
C	62.8	37.2	
R	34.1	46.3	19.5
Total	39.2	44.0	16.8

M Score = 77.6

72 h TOTL

Best Track	%0	%1	%2
L	70.7	26.8	2.4
C	23.3	76.7	
R	0.0	12.2	87.8
Total	31.2	39.2	29.6

M Score = 98.4

72 h CY50

Best Track	%0	%1	%2
L	36.6	24.4	39.0
C	30.2	69.8	
R	58.5	34.1	7.3
Total	41.6	43.2	15.2

M Score = 73.6

Figure A.29 As in Fig. A.1, except for size > 220 n mi.

24 h OTCM (Best Track)

	%0	%1	%2
S	60.0	37.5	2.5
C	39.5	60.5	
F	33.3	40.5	26.2
Total	44.0	46.4	9.6

M Score = 65.6

24 h REC (Best Track)

	%0	%1	%2
S	27.5	52.5	20.0
C	60.5	39.5	
F	38.1	45.2	16.7
Total	42.4	45.6	12.0

M Score = 69.6

24 h TOTL (Best Track)

	%0	%1	%2
S	27.5	45.0	27.5
C	32.6	67.4	
F	76.2	23.8	0.0
Total	45.6	45.6	8.8

M Score = 63.2

24 h CY50 (Best Track)

	%0	%1	%2
S	50.0	30.0	20.0
C	34.9	65.1	
F	35.7	23.8	40.5
Total	40.0	40.0	20.0

M Score = 80.0

48 h OTCM (Best Track)

	%0	%1	%2
S	48.8	41.5	9.8
C	53.5	46.5	
F	48.8	43.9	7.3
Total	50.4	44.0	5.6

M Score = 55.2

48 h REC (Best Track)

	%0	%1	%2
S	19.5	48.8	31.7
C	53.5	46.5	
F	58.5	39.0	2.4
Total	44.0	44.8	11.2

M Score = 67.2

48 h TOTL (Best Track)

	%0	%1	%2
S	31.7	43.9	24.4
C	51.2	48.8	
F	70.7	26.8	2.4
Total	51.2	40.0	8.8

M Score = 57.6

48 h CY50 (Best Track)

	%0	%1	%2
S	61.0	14.6	24.4
C	11.6	88.4	
F	17.1	39.0	43.9
Total	29.6	48.0	22.4

M Score = 92.8

72 h OTCM (Best Track)

	%0	%1	%2
S	48.8	39.0	12.2
C	27.9	72.1	
F	46.3	41.5	12.2
Total	40.8	51.2	8.0

M Score = 67.2

72 h REC (Best Track)

	%0	%1	%2
S	19.5	36.6	43.9
C	46.5	53.5	
F	53.7	43.9	2.4
Total	40.0	44.8	15.2

M Score = 75.2

72 h TOTL (Best Track)

	%0	%1	%2
S	53.7	46.3	0.0
C	32.6	67.4	
F	24.4	51.2	24.4
Total	36.8	55.2	8.0

M Score = 71.2

72 h CY50 (Best Track)

	%0	%1	%2
S	68.3	4.9	26.8
C	20.9	79.1	
F	17.1	22.0	61.0
Total	35.2	36.0	28.8

M Score = 93.6

Figure A.30 As in Fig. A.2, except for size > 220 n mi.

LIST OF REFERENCES

Chan, J. C. L., 1982: On the physical processes responsible for tropical cyclone motion. Atmospheric Science Paper No. 358, Colorado State University, Ft. Collins, CO, 200 pp.

--------------, W. M. Gray and S. Q. Kidder, 1980: Forecasting tropical cyclone turning motion from surrounding wind and temperature fields. *Mon. Wea. Rev., 108*, 778-792.

--------------, B. J. Williams and R. L. Elsberry, 1986: The performance of the Nested Tropical Cyclone Model as a function of five storm-related parameters. Submitted for publication.

Elsberry, R. L., and J. E. Peak, 1986: An evaluation of tropical cyclone forecast aids based on cross-track and along-track components. *Mon. Wea. Rev., 114*, 147-155.

Jarrell, J. D., S. Brand and D. S. Nicklin, 1978: An analysis of western North Pacific tropical cyclone forecast errors. *Mon. Wea. Rev., 106*, 925-937.

Joint Typhoon Warning Center, 1985: Annual Tropical Cyclone Report. U.S. Naval Oceanography Command Center, Joint Typhoon Warning Center, Guam, COMNAV MARINAS, Box 17, FPO San Francisco 96630.

Merrill, R. T., 1982: A comparison of large and small tropical cyclones. Atmospheric Science Paper No. 352, Colorado State University, Ft. Collins, CO, 71 pp.

Neumann, C. J., and P. W. Leftwich, 1977: Statistical guidance for the prediction of eastern North Pacific tropical cyclone motion, Part 1. NOAA Tech Memo, WR-124 {NTIS PB-272 661/OGI}, National Weather Service Western Region, Salt Lake City, Utah, 32 pp.

--------------, and J. M. Pelissier, 1981a: Models for the prediction of tropical cyclone motion over the North Atlantic; An operational evaluation. *Mon. Wea. Rev., 109*, 522-538.

--------------, and J. M. Pelissier, 1981b: Analysis of Atlantic tropical cyclone forecast errors, 1970-1979. *Mon. Wea. Rev., 109*, 1248-1265.

Peak, J. E., and R. L. Elsberry, 1982: A simplified statistical post-processing technique for adjusting tropical cyclone tracks. *Papers in Meteor. Res., 5*, 1-14.

----------, and R. L. Elsberry, 1985: Objective selection of optimum tropical cyclone guidance using a decision-tree methodology. Extended abstracts, 16th Tech. Conf. on Hurricanes and Tropical Meteorology, Houston, Amer. Meteor. Soc., 97-98.

----------, and R. L. Elsberry, 1986: Prediction of tropical cyclone turning and acceleration using empirical orthogonal function representations. *Mon. Wea. Rev., 114*, 156-164.

-----------, W. E. Wilson, R. L. Elsberry and J. C. L Chan, 1986: Forecasting tropical cyclone motion using empirical orthogonal function representations of the environmental wind fields. Submitted for publication.

Preisendorfer, R. W., and C. D. Mobley, 1982: Data intercomparison theory II: Trinity statistics for location, spread and pattern differences. NOAA Tech. Memo., ERL PMEL-39, Pacific Marine Environ. Lab., Seattle, WA, 91 pp.

Renard, R. J., and W. N. Bowman, 1976: The climatology and forecasting of eastern North Pacific Ocean tropical cyclones. NEPRF Tech. Pap. No. 7-76 (NTIS AD-A031 194/4GI), Naval Environmental Prediction Research Facility, Monterey, CA, 79 pp.

Shaffer, A. R., and R. L. Elsberry, 1982: A statistical climatological tropical cyclone track prediction technique using an EOF representation of the synoptic forcing. *Mon. Wea. Rev.*, *110*, 1945-1954.

Shewchuk, J. D., and R. L. Elsberry, 1978: Improvement of short-term dynamical tropical cyclone motion prediction by initial field adjustments. *Mon. Wea. Rev.*, *106*, 713-718.

Thompson, W. J., R. L. Elsberry and R. G. Read, 1981: An analysis of eastern North Pacific tropical cyclone forecast errors. *Mon. Wea. Rev.*, *109*, 1930-1938.

Tsui, T. L., 1984: A selection technique for tropical cyclone objective aids. Postprints, 15th Conf. on Hurricanes and Tropical Meteorology, Amer. Meteor. Soc., Boston, 40-44.

Williams, B. J., 1986: Effects of storm-related parameters on the accuracy of the Nested Tropical Cylone Model. M.S. thesis, Naval Postgraduate School, Monterey, CA, 107 pp.

Xu, J., and W. M. Gray, 1982: Environmental circulations associated with tropical cyclones experiencing fast, slow and looping motion. Atmospheric Science Paper No. 346, Colorado State University, Ft. Collins, CO, 162 pp.

Xu, Y., and C. J. Neuman, 1985: A statistical model for the prediction of western North Pacific tropical cyclone motion (WPCLPR). NOAA Tech. Memo. NWS NAC 28, 30 pp.

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